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THE
CANADIAN
WIND ENERGY
ASSOCIATION

Proceedings

Canadian Wind Energy Conference '85

December 9-10, 1985
Ottawa, Ontario, Canada

Sponsored by
Energy, Mines and Resources Canada
National Research Council of Canada

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PROCEEDINGS OF THE FIRST NATIONAL CONFERENCE
OF THE
CANADIAN WIND ENERGY ASSOCIATION (CANWEA)

Ottawa, Ontario December 9 - 10, 1985

Edited by:
Malcolm Lodge

Produced by:
Passmore Associates
Ottawa, Ontario

Sponsored by:
Energy, Mines, and Resources Canada
National Research Council Canada

March 1986

ACKNOWLEDGEMENT

The Canadian Wind Energy Association (CanWEA) would like to thank all of those who devoted their efforts to make this first conference of our newly formed association a success:

Vince Lacey of Indal Technologies who coordinated much of the program planning;

Alex Printzios of Adecon Energy Systems who managed the financial activity;

Malcolm Lodge of the Atlantic Wind Test Site who chaired the conference;

Passmore Associates, our conference organizers, who exceeded our demands for an efficient and smoothly run conference; and

our generous sponsors, Energy, Mines and Resources Canada and the National Research Council of Canada, who made the conference and the publication of these proceedings possible.

Our many thanks to our loyal members who attended, many of whom presented interesting and informative papers; to the exhibitors; and to our American Wind Energy Association (AWEA) colleagues who visited us.

CANADIAN WIND ENERGY ASSOCIATION
FIRST ANNUAL WIND ENERGY CONFERENCE

PROCEEDINGS

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Minutes from the CanWea Directors' Meeting

INTRODUCTION

The objective of the Canadian Wind Energy Association (CanWEA) is to assist and encourage the development of a Canadian wind energy industry. This first CanWEA conference is one of what we hope are many more meetings and workshops to facilitate the presentation, discussion, and exchange of state-of-the-art information in this expanding and exciting field.

Wind energy, often termed the darkhorse in the race to develop renewable energies is clearly in a leading position with respect to performance, reliability, and cost effectiveness. Canadian industry, however, has some major hurdles to clear if we wish to continue to be counted as a contender. CanWEA offers its support to the industry and government and other organizations striving to develop the technology.

Sincerely,

Malcolm A. Lodge, P. Eng.
CanWEA President 1985

THE R.J. TEMPLIN AWARD

Commencing with our first Canadian Wind Energy Association conference, the directors of CanWEA will award the R.J. Templin award for outstanding contribution to the development of wind energy technology to a deserving individual or organization.

We are proud to name the award in honour of Jack Templin of the National Research Council, National Aeronautic Establishment, Low Speed Aerodynamics Laboratory who has contributed so greatly to Canadian wind energy technology development.

Thanks and congratulations this year to our first recipient, Marcus (Marc) Chappell, who as Assistant Director of NRC's Energy Division and Manager of the Division's Wind Energy Research and Development Program, has guided and sometimes prodded us towards the many satisfying goals we have achieved.

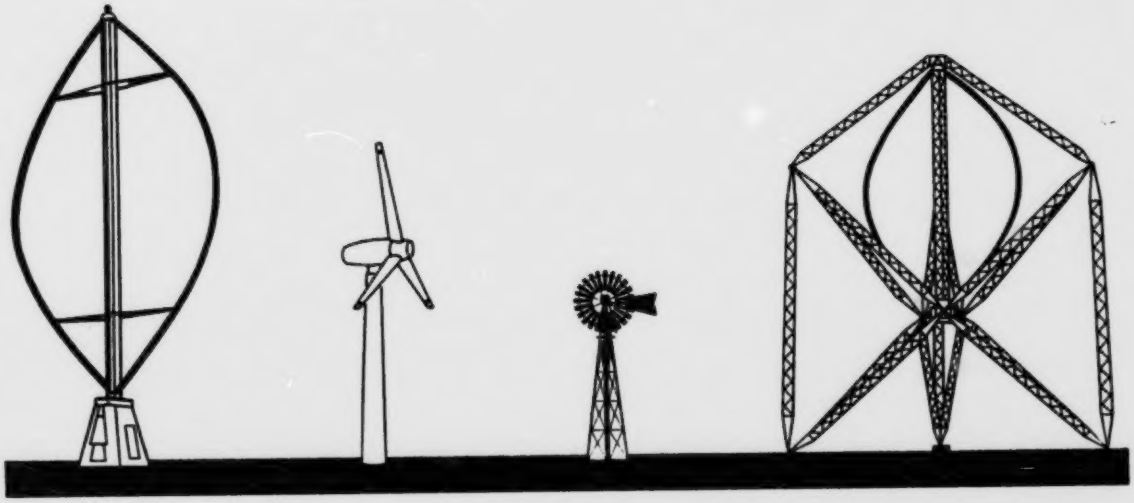
We wish also to offer special thanks this year to Jack Templin for speaking to us so entertainingly at the conference banquet.

The
R. J. TEMPLIN AWARD

For outstanding contributions
to the development of
Canadian wind energy technology

To

Marcus S. Chappell



Presented by :

The Canadian Wind Energy Association
1st Annual Conference, Ottawa, Ontario
December 9, 1985

OPENING REMARKS

OPENING REMARKS

CanWEA Conference
December 9 - 10

D. L. P. Strange

Director

Renewable Energy Division

Good morning ladies and gentlemen.

I very much appreciate the opportunity to be with you this morning for the opening of the first official Canadian Wind Energy Association conference. I am happy to see so many people attending this conference especially during such a very active period of the year.

I remember at last year's conference in Toronto that there were a lot of concerns and uncertainties with regard to the federal government's position on wind energy and renewable energy in general. We had just come through a series of a major cuts which included the elimination of NRC's energy Research and Development Program. I must admit that things did look pretty grim for a while. But a lot of people did not give up. People like yourselves, with a commitment to the field, began to take action and before too long an organized voice representing the Conservation and Renewable Energy industry in Canada was in place and actively speaking out on behalf of this industry and the technologies that were being developed. A lot of credit is due to the organizers and many participants in that council. I believe that the fact that we are here today, is largely due to the hard work and eventual success of that group, the Conservation and Renewable Energy Industry Council.

As many of you know, in May of this year a decision was announced which gave EMR the mandate for continuing the support of renewable energy. With that new responsibility we at EMR began to review the previous programs in order to make recommendations for future activities. Recognizing that we would need some help in this job we came to you with several key issues to be considered and many questions to be answered. We wanted you to become partners with the federal government in the undertaking of the redirection of the efforts for the development of renewable energy.

We held a formal meeting in Montebello two months ago in order to bring us all under one roof to tackle the future together and I think that the meeting was a good beginning for the partnership that we were trying to cultivate. I was impressed by the wind community's willingness to participate in this role and the enthusiasm and dedication that has been demonstrated during this hectic year.

I really must congratulate you for your efforts over the past year. Despite the uncertainties in federal government programs, the wind industry has continued and has progressed significantly over the last year. More wind turbines have been installed, improvements on existing machines have been made, and new companies have been formed.

Another major step has been taken in defining good applications for wind energy in Canada. It is not enough just to have a good piece of equipment - we must have the right application as well. I believe we are starting to think this way in Canada and I expect to see our product lines evolving to meet today's wind energy needs.

I would now like to detail some of the events that have taken place over the last year here at EMR to bring you up to date. In the May announcement a new initiative called NCAEI - the National Conservation and Alternative Energy Initiative - was established with a funding level of $300 million over the next 3 years. It eliminated direct grants to energy users and concentrated more on support programs for energy research and demonstration, technology transfer and improving consumer awareness as means to encourage investment in energy efficiency.

The alternative energy components of NCAEI are to support the RD&D needed to address the technical problems and improve the competitiveness of these technologies. The financial support is meant to overcome such barriers as market price distortions, lack of information to investors, high perceived risks to users and small under capitalized industries. In other words, our new effort will be concentrating on developing the commercial potential of renewable energy technologies which have markets both in Canada and abroad.

The NCAEI is also accompanied by an effort to increase federal/provincial collaboration in the energy sector. Specific agreements are now under negotiation with the provinces and while the final impact of these negotiations is not clear in all cases, for you it hopefully will mean better access to programs at both level of government and a better coordination of these programs.

In October of this year it was decided to organize a two day workshop in Montebello, Québec, to seak your input for the planning and implementation of our R&D programs in renewable energy. The wind energy subgroup was composed of 12 participants representing the manufacturing industry, distributors of wind equipment, R&D performers, testing agencies, and government representatives. Many subjects were covered including the management process, information dissemination and the proposed technology goal that we should set. Amongst the results of that workshop was the suggestion to implement a management structure which would incorporate technical advisory committees in each specific technology. It was also strongly recommended that a request for proposals be issued as soon as possible.

I believe we reacted quickly and positively to those suggestions. Following the workshop, a draft version of the Wind Energy R&D program was prepared in which specific goals and objectives as well as priority areas were defined. A Wind Energy Technical Advisory Committee has been formed and will meet for the first time Thursday December 12, 1985. A general request for proposals will also soon be issued covering wind and other renewable energy technologies.

Copies of this RFP are available during this conference for anyone of you who might be interested in an advance copy. Proposals must be received by January 31st and review is scheduled for February. It is anticipated that contracts will be in place by March or April.

I would like to think that EMR has been responsive to your needs as an industry. I know that there will likely be those of you who feel that we've lost our momentum, or that there's not enough money, or other negative criticisms. But now is not the time for complaining. For one thing, the political climate is not right. For another, I think what we have is a good, comprehensive program - we have a clear mandate for at least three years and probably five; we also offer you "one stop shopping" since Research, Development and Demonstration support is now available to you under one group at EMR; as well we hope to continue to work closely with some of the key individuals at NRC to ensure that that expertise remains available to us all; and furthermore, and this is probably the most important benefit we can offer, we are committed to working with you as a partner to realize success for you and your company. If you have a good idea, I can guarantee you that we will act as your agent to obtain the maximum level of support within our program and the other federal programs as well.

Now while I cannot hope to see instant success stories for every wind energy company in Canada, I must remind you that time is a bit tight and we would like to have a success story to tell in the near future. Therefore, I look forward to receiving some imaginative, well-thought out proposals from you and I eagerly await for the opportunity to report your successes to our political masters.

Energy conferences provide a forum for discussion and for exchange of information. During the next two days of the conference many papers will be presented covering a variety of subjects of interest to the wind community. Product development, economic consideration, financial incentives, research and development activities, government programs, standard development, all these subjects and others will be presented and discussed and I look forward to a productive two days here in Ottawa.

I would like to take this opportunity to thank the CanWEA directors for their excellent work and also to congratulate them on their re-election. We sometimes have the tendency to forget the hard work and long hours that are needed to effectively manage an association, and the skills that are necessary to keep together all you individually-minded people with your many different interests and goals. CanWEA is celebrating its first anniversary today and I would like to wish its members and directors the best of luck for next year and the years to come.

TECHNICAL PAPERS

RESEARCH DEVELOPMENTS

NRC COMPUTER CODES FOR WIND ENERGY CALCULATIONS

By
M.J. Nituch
Low Speed Aerodynamics Laboratory
National Aeronautical Establishment

Presented
at
the
Canadian Wind Energy Conference 1985

Ottawa, Ontario, Canada
December 1985

1.0 INTRODUCTION

The involvement of Low Speed Aerodynamics Laboratory staff in the development of the Darrieus-type vertical-axis wind turbine began with the early experimental work of South and Rangi (1)* and (2). The development of a theoretical method capable of predicting turbine aerodynamic loads and performance began with the publication of a simple single streamtube momentum-based theory by Templin (3). Subsequent work led to the development of the Double-Multiple Streamtube method by Templin (4). This method has formed the basis for the majority of vertical-axis prediction methods currently employed in Canada, (5), (6), (7).

At the Low Speed Aerodynamics Laboratory, this method was incorporated into a computer program by GasTOPS Ltd. and installed on the in-lab PDP 11/44 computer system (refs. (8) to (11), inclusive) .

This program, extensively modified, has become the central element of a suite of computer codes used for wind energy calculations.

The formal documentation for this suite of programs consists of two reports:

LTR-LA-278 - Users' Manual

LTR-LA-279 - Program Manual

The first report contains brief descriptions of the codes and instructions on how to run them. Examples of input and output are provided, where required.

The second report contains more detailed descriptions of the individual codes, including complete listings. This part would be of particular interest to individuals wishing to modify or extend the program codes. Both of these reports are in the final stages of preparation.

The purpose of the present report is to describe this suite of programs and provide some examples of their use. The individual programs are listed in Table 1 together with a brief statement of their purpose. The inter-relationship between these codes is shown in Figure 1. As may be seen, the suite of programs is centered on MNGASTOP, the performance and loads prediction program. Other programs are designed as pre-or post-processors which either prepare data for, or access data from MNGASTOP.

The present paper will concentrate on the performance of the central element of this suite of codes, MNGASTOP.

---

* Numerals in brackets designate references as listed at the end of this paper.

TABLE I

WIND ENERGY COMPUTER CODES

Program Name	Function	Level Number	Date
INPUTBILD	Interactively builds a dataset file containing geometrical data to be used as input to MNGASTOP	164	26 June 85
MNGASTOP	Modified version of GasTOPS Ltd. performance and loads calculation program	*	*
MNLOADS	Rearrange blade element loads output from MNGASTOP program to a more useable form.	20	12 June 85
ENERCALC	Compute yearly energy output for specified power vs. wind speed curve and wind regime with Weibull parameters as input.	131	30 Apr. 85
CPCALC	Compute non-dimensional power characteristics from tabulated dimensional power curve	14	17 Sept. 85

NOTE: * The latest version of MNGASTOP is comprised of 3 modules which are used in an overlay manner. This use is transparent to the user. A single version number or date would not, therefore, apply.

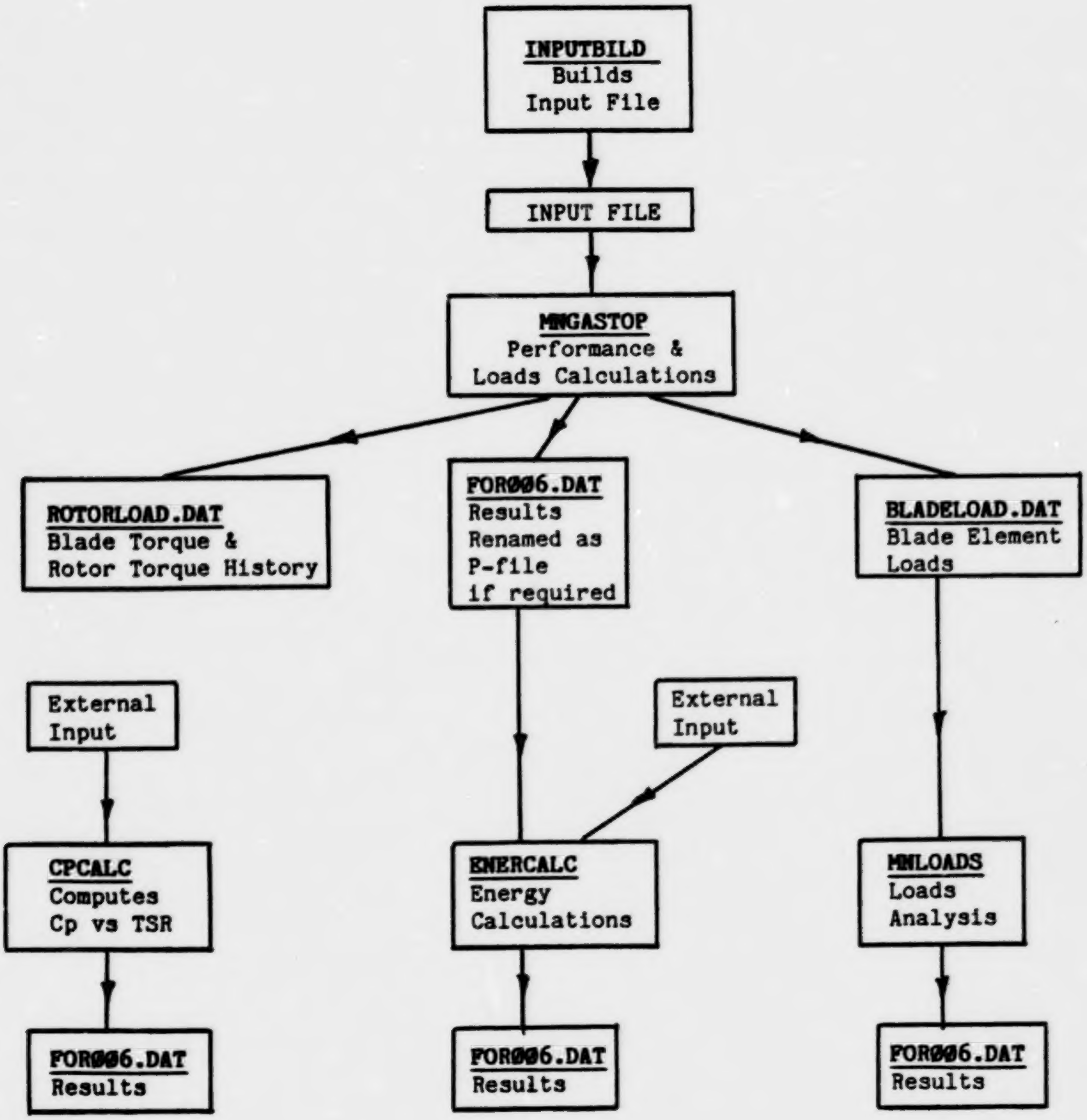

INPUTBILD
Builds
Input File
INPUT FILE
MNGASTOP
Performance &
Loads Calculations
ROTORLOAD.DAT
Blade Torque &
Rotor Torque History
FOR006.DAT
Results
Renamed as
P-file
if required
BLADELOAD.DAT
Blade Element
Loads
External
Input
External
Input
CPCALC
Computes
Cp vs TSR
ENERCALC
Energy
Calculations
MNLOADS
Loads
Analysis
FOR006.DAT
Results
FOR006.DAT
Results
FOR006.DAT
Results

FIGURE 1
Relationship Between Computer Codes

2.0 The MNGASTOP Code

The MNGASTOP code has been written to compute the aerodynamic loads and performance of vertical-axis wind turbines. As mentioned previously, this code is an extensively modified version of the GasTOPS codes, and is based on the Double Multiple Streamtube method developed by Templin. In this method, the induced velocity on a blade element is determined by the momentum loss due to the elemental drag at that position. For any blade element at a particular position, an iterative procedure is required for closure. Separate calculations are made for the upstream and downstream positions of the blade. It is assumed that the effects on any blade element are independent of the effects on adjacent elements, or blade position.

Within the program is the capability of dealing with a variety of computational options. These options can be broken down into four main areas:

1) Turbine geometry including a description of the wind shear model,

2) Range of flow conditions for which the calculations are to be performed,

3) Selection of the stall model to be used,

and 4) Selection of the output level to be produced.

The turbine geometry information is contained in an input dataset which is generated by running the INPUTBILD code and interactively responding to the questions as presented. A list of the turbine geometry parameters which are user-specified is given in Table II. The remaining options are specified by the user as replies to questions posed by the system while running MNGASTOP. Flow conditions are specified in either windspeed or tip-speed-ratio terms for dimensional or non-dimensional calculations, respectively. The complete range of conditions is specified by giving initial, final and increment values. Calculations are performed at initial and final values and at equal intervals in between.

TABLE II

Wind Turbine Geometry Specification

- Dimensional / Non-Dimensional Input and Output
- Turbine Geometry
  - Height or Height-to-Diameter Ratio
  - Diameter or Solidity
  - Elevation at Equator (in dimensional or non-dimensional form)
  - Number of Blades
  - Rotational Speed
  - or Mean Equatorial Reynolds Number
- Blade Shape
  - Parabolic or User-Specified Coordinates
- Constant Chord and Toe-in Angle
  - or User-Specified Variation
- Chord at Equator
- Toe-in at Equator
- Wind Shear Model
  - Uniform
  - Log Law
  - Power Law
- Density
- Viscosity
- Number of Slices (Fractions of Rotor Height)
- Number of Sectors (Azimuthal Positions)
- Airfoil Section Zero Lift Drag Coefficient (C_{D_o})
- Airfoil Section (choice of 5)

The second option to be chosen by the user is that of stall model. A variety of stall models have been included in the code. These are shown in Table III, and are all variations on the Gormont stall model (ref. 12) which has been in use for some time by a variety of researchers. The complete list of options looks rather daunting, but includes some options which are at the moment of only academic interest. A list of option numbers equivalent to some better known codes produced by other researchers is shown in Table IV. Again, the selection of stall model is made in response to an interactive query from the MNGASTOP code.

Some examples of the effect of a choice of dynamic stall model are shown in the next few Figures. Figure 2 shows the results for the Magdalen Islands wind turbine at 29.4 RPM. The curves shown here include predictions made with the following stall models.

1) static stall,
2) dynamic stall - VAWTAERO model,
3) dynamic stall - Gormont C_L and C_D models,

and 4) dynamic stall - only the C_L part of the Gormont model.

This figure shows the effect of several changes in the model. The first thing to note is that the static stall model does not match the experimental data. Of the dynamic stall models, the full Gormont with both lift and drag corrections provides the best fit to the data. It is interesting to note that the drag correction accounts for approximately 1/2 the difference between the full Gormont prediction and the static model case. The VAWTAERO model underpredicts the test data. It is somewhat surprising that the full Gormont model predicts the performance so well, especially since the drag model is so physically unrealistic.

Figure 3 shows the same comparison for the Magdalen Islands VAWT at 36.6 RPM. Again, the full Gormont model results show the closest agreement with experiment. The data do show that even the Gormont model underestimates the power output at windspeeds over which the dynamic stall model is effective. This behaviour seems to suggest a Reynolds Number effect that is not being adequately modelled in the treatment of airfoil section data.

TABLE III

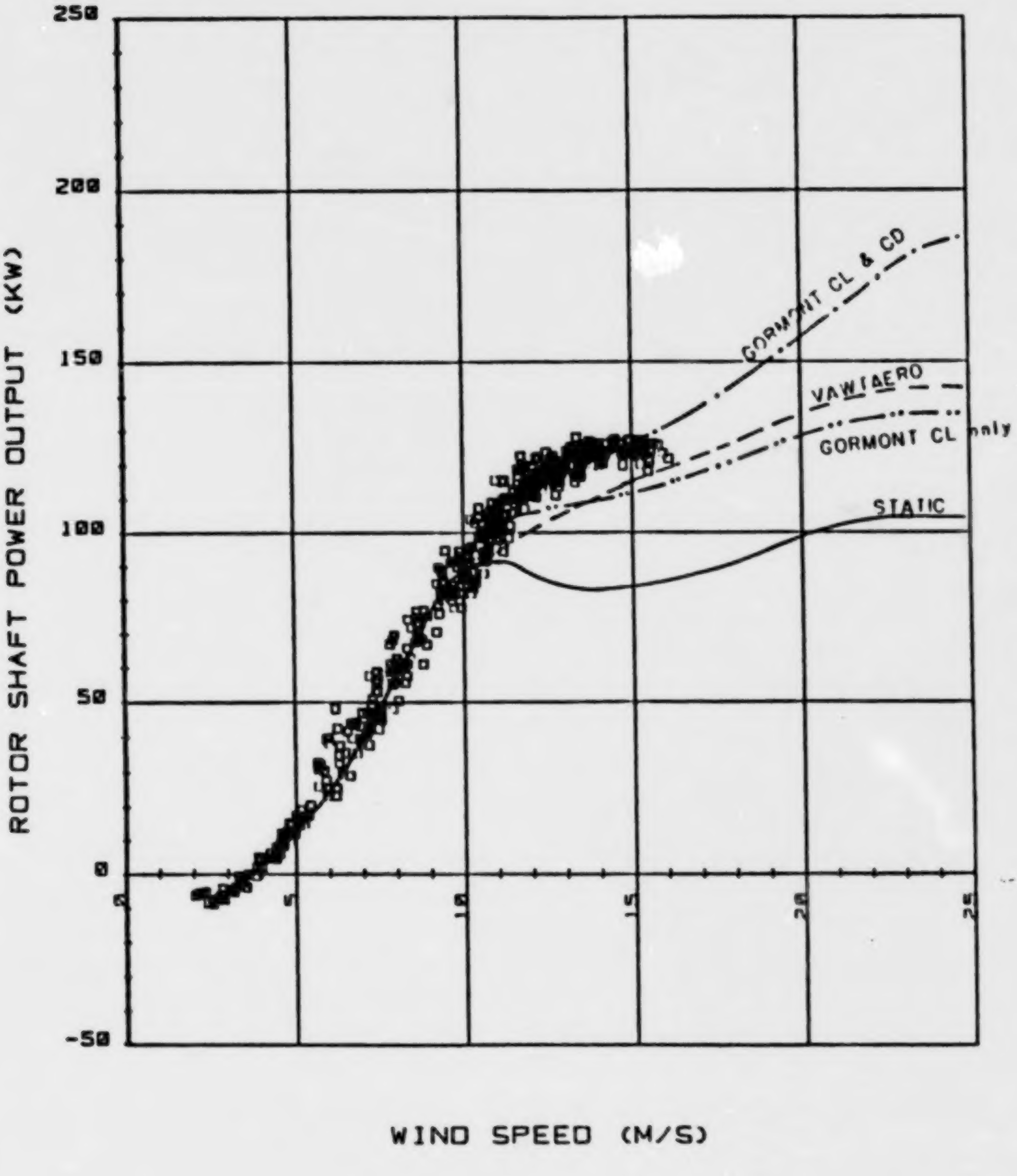
Summary of Stall Models Available

AREA MODELLED	DETAILS OF MODEL	STALL MODEL OPTION NUMBER													
		STATIC			DYNAMIC										
		0	10	20	1	2	3	4	5	51	52	6	7	8	9
CONVERGENCE CRITERION	Maximum Deviation = 0.1% V upstream	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
	Maximum Deviation = 0.1% R Ω/V upstream			✓			✓								
LIFT MODEL	Static Data	✓	✓	✓							✓				
	Gormont Variants:														
	.- γ_2 is function of t/c only				✓										
	.- γ_2 is function of t/c and Mach					✓		✓	✓	✓		✓	✓	✓	✓
	.- γ_2 is fixed						✓								
	.- $\Delta\alpha$ stall = 0 if $\dot{\alpha}$ is 0							✓	✓	✓					
	.- $\Delta\alpha$ stall $\neq$ 0 if $\dot{\alpha}$ is 0				✓	✓	✓					✓	✓	✓	✓
	.- Tapering : Templin						✓								
	: Massé											✓	✓	✓	
	: Nituch							✓							
DRAG MODEL	C_{D_0} fixed	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓		✓
	C_{D_0} function of Reynolds Number		✓									✓		✓	
	Static Data	✓	✓	✓	✓	✓	✓	✓		✓				✓	✓
	Gormont Drag Model								✓		✓	✓	✓		
	Tapering : Massé Taper											✓	✓		

TABLE IV

Commonly Used Stall Model Options

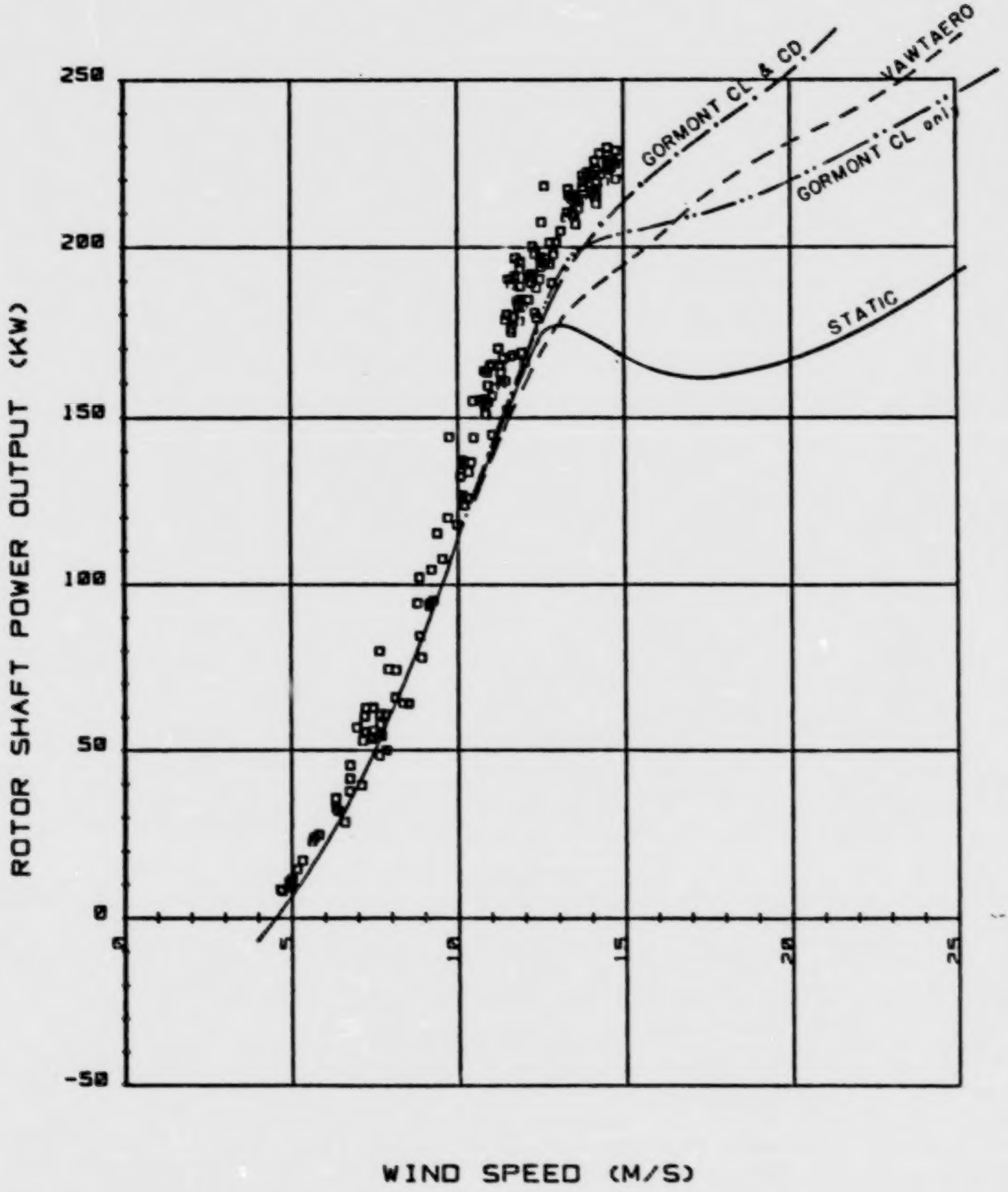
PROGRAM	STALL MODEL	OPTION NUMBER
VAWTAERO	STATIC	20
	DYNAMIC	3
MADMD	STATIC	10
	DYNAMIC	6
GORMONT	DYNAMIC C_L and C_D	5
GORMONT	DYNAMIC C_L only	51



MAGDALEN ISLANDS VAWT

ROTOR SHAFT POWER vs. WIND SPEED
ROTOR SPEED : 29.4 RPM

Figure 2



MAGDALEN ISLANDS VAWT

ROTOR SHAFT POWER vs. WIND SPEED
ROTOR SPEED : 36.6 RPM

Figure 3

Returning to the MNGASTOP code, the remaining options involve the choice of level of output to be produced by the code. The program will, in any event, output the aerodynamic performance, that is, power versus windspeed for all calculations. The option exists however, to produce the following additional output:

1) Convergence history if iterations for any streamtube exceed 10,

2) Blade element aerodynamic loads for a complete revolution, for one windspeed only,

and 3) Single blade and complete rotor aerodynamic torque, downwind and cross wind forces, including the first 10 pairs of Fourier coefficients for the single blade torque.

Again, these are chosen either singly or in combination by an interactive response to questions posed by the computer code. Due to time limitations, discussion of the convergence history option will not be included here.

The user may select an option that provides for the production of aerodynamic loads. This option requires the use of a post-processor code, MNLOADS, to reformat the data into an easily readable form. The data available by using this procedure are shown in Table V. These output are presented in tabular form as functions of azimuth, and fraction of rotor height for the upper half of the rotor only. An example of the output of the tangential force per unit span is shown in Figure 4. This is for the Magdalen Islands wind turbine using a static stall model. These loads are for a windspeed of 14 m/sec which is near cutout. As may be seen, the tabular form is well suited to a contour map presentation. The results presented here indicate a large region of positive (power producing) force in the first quadrant, with the blade advancing into the wind. With the exception of a few small areas where the blade is aligned with the wind, and near the upper half of the rotor, power is produced over the whole rotation.

The final option available in MNGASTOP is the single blade and complete rotor loads and torque option. A list of the output resulting from the use of this option is shown in Table VI. As an example of the output produced when this option is selected, Figure 5 shows the variation of the average single blade torque and of the amplitudes of the first two harmonics as a function of windspeed, calculated for the Magdalen Islands wind turbine. Predictions have been made using three stall models: static, full Gormont with dynamic lift and drag corrections and a partial Gormont model with only the lift correction. As may be seen, the effect of a change in the stall model is proportionally greater on the harmonic amplitudes than on the mean torque amplitude.

TABLE V

Output from the MMLOADS Code

- Tangential force per unit span, (N/m)
- Normal force per unit span, (N/m)
- Tangential force coefficient, based on windspeed
- Normal force coefficient, based on windspeed
- Angle of attack
- Lift coefficient of blade element at angle of attack
- Drag coefficent of blade element at angle of attack
- Local chord Reynolds number.

TABLE VI

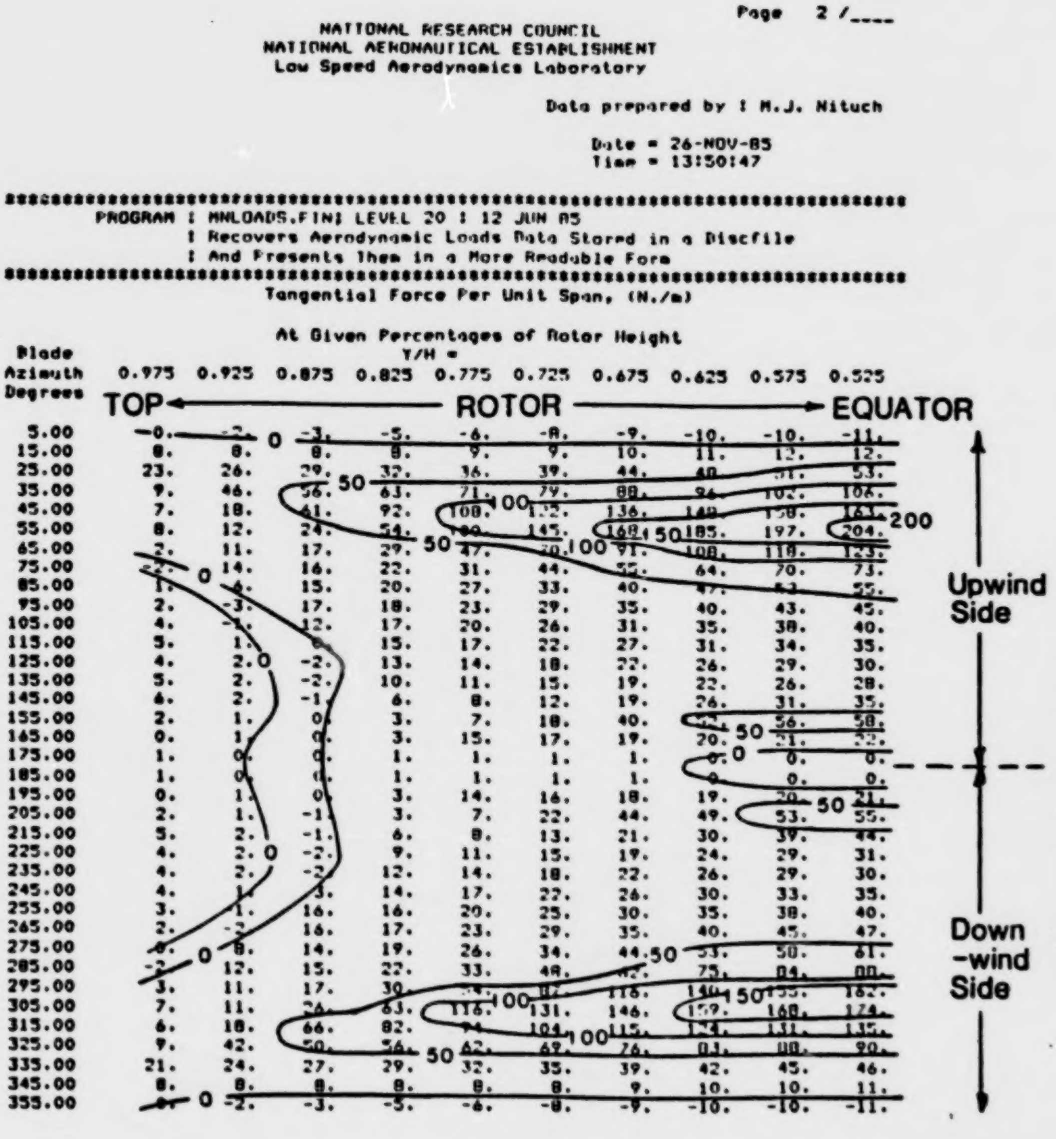
Single Blade and Rotor Loads Output

Single Blade Output:

- Total Blade Torque, as function of Azimuth
- Total Blade Bearing Load, Magnitude and Direction, as function of Azimuth
- Total Blade Torque, first 10 Fourier Coefficients

Total Rotor Output:

- Total Rotor Torque, as function of Azimuth
- Total Rotor Bearing Load, Magnitude and Direction, as function of Azimuth



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                                                              Page   2 /____
                    NATIONAL RESEARCH COUNCIL
                NATIONAL AERONAUTICAL ESTABLISHMENT
                  Low Speed Aerodynamics Laboratory

                                          Data prepared by : M.J. Nituch

                                              Date = 26-NOV-85
                                              Time = 13:50:47

#############################################################################
       PROGRAM : MNLOADS.FIN; LEVEL 20 : 12 JUN 85
                 : Recovers Aerodynamic Loads Data Stored in a Discfile
                 : And Presents Them in a More Readable Form
#############################################################################
                    Tangential Force Per Unit Span, (N./m)

                   At Given Percentages of Rotor Height
Blade                                Y/H =
Azimuth  0.975  0.925  0.875  0.825  0.775  0.725  0.675  0.625  0.575  0.525
Degrees
   5.00    -0.    -2.    -3.    -5.    -6.    -8.    -9.   -10.   -10.   -11.
  15.00     8.     8.     8.     8.     9.     9.    10.    11.    12.    12.
  25.00    23.    26.    29.    32.    36.    39.    44.    48.    51.    53.
  35.00     9.    46.    56.    63.    71.    79.    88.    96.   102.   106.
  45.00     7.    18.    41.    92.   108.   122.   136.   148.   158.   163.
  55.00     8.    12.    24.    54.   100.   145.   168.   185.   197.   204.
  65.00     2.    11.    17.    29.    47.    70.    91.   108.   118.   123.
  75.00    -2.    14.    16.    22.    31.    44.    55.    64.    70.    73.
  85.00     1.    -6.    15.    20.    27.    33.    40.    47.    53.    55.
  95.00     2.    -3.    17.    18.    23.    29.    35.    40.    43.    45.
 105.00     4.    -1.    12.    17.    20.    26.    31.    35.    38.    40.
 115.00     5.     1.     6.    15.    17.    22.    27.    31.    34.    35.
 125.00     4.     2.    -2.    13.    14.    18.    22.    26.    29.    30.
 135.00     5.     2.    -2.    10.    11.    15.    19.    22.    26.    28.
 145.00     6.     2.    -1.     6.     8.    12.    19.    26.    31.    35.
 155.00     2.     1.     0.     3.     7.    18.    40.    52.    56.    58.
 165.00     0.     1.     0.     3.    15.    17.    19.    20.    21.    22.
 175.00     1.     0.     0.     1.     1.     1.     1.     0.     0.     0.
 185.00     1.     0.     0.     1.     1.     1.     1.     0.     0.     0.
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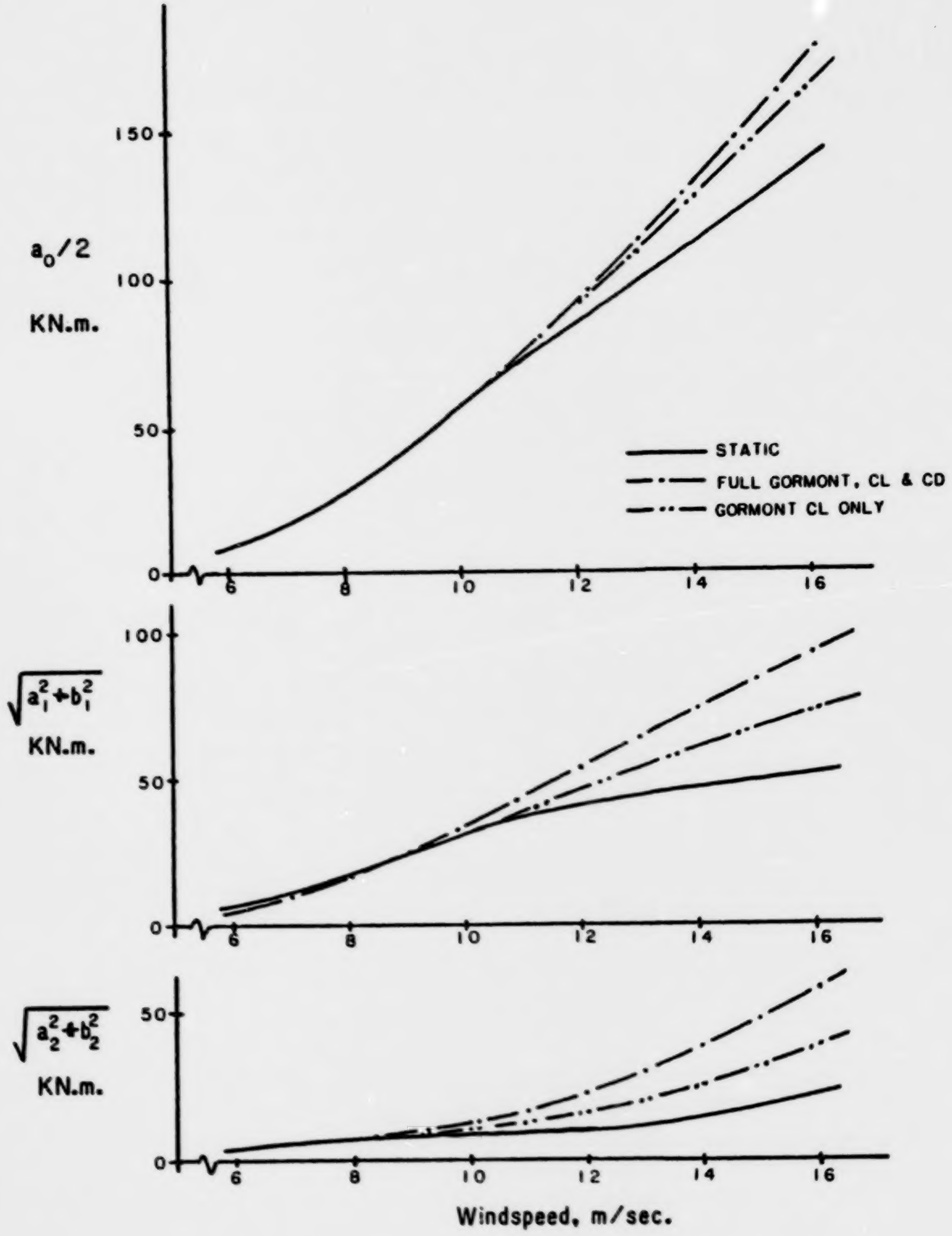
 205.00     2.     1.    -1.     3.     7.    22.    44.    49.    53.    55.
 215.00     5.     2.    -1.     6.     8.    13.    21.    30.    39.    44.
 225.00     4.     2.    -2.     9.    11.    15.    19.    24.    29.    31.
 235.00     4.     2.    -2.    12.    14.    18.    22.    26.    29.    30.
 245.00     4.     1.     3.    14.    17.    22.    26.    30.    33.    35.
 255.00     3.     1.    16.    16.    20.    25.    30.    35.    38.    40.
 265.00     2.    -2.    16.    17.    23.    29.    35.    40.    45.    47.
 275.00    -0.     8.    14.    19.    26.    34.    44.    53.    58.    61.
 285.00    -2.    12.    15.    22.    33.    48.    62.    75.    84.    88.
 295.00     3.    11.    17.    30.    54.    87.   118.   140.   155.   162.
 305.00     7.    11.    26.    63.   116.   131.   146.   159.   168.   174.
 315.00     6.    18.    66.    82.    94.   104.   115.   124.   131.   135.
 325.00     9.    42.    50.    56.    62.    69.    76.    83.    88.    90.
 335.00    21.    24.    27.    29.    32.    35.    39.    42.    45.    46.
 345.00     8.     8.     8.     8.     8.     8.     9.    10.    10.    11.
 355.00    -0.    -2.    -3.    -5.    -6.    -8.    -9.   -10.   -10.   -11.
```

Tangential Force per unit Blade Length, (N./m.)
Magdalen Islands VAWT , 29.4 RPM

Figure 4



Fourier Coefficients of Single Blade Torque
Magdalen Islands VAWT, 29.4 RPM

Figure 5

3.0 CONCLUDING REMARKS

This paper was intended to serve as an introduction to the suite of computer codes in use at Low Speed Aerodynamics at NRC. The emphasis in this paper was on the central element of this suite, the MNGASTOP loads and performance prediction program. The examples presented showed the variety of options that are available.

The codes described in this paper can be made available to interested users. These are asked to contact the author for further information.

The codes described in this report have been used and tested in a variety of tasks over the past year, not only by the author of this report, but also by his colleagues. Although every effort has been made to ensure the accuracy and veracity of the programming, no responsibility for such can be assumed by the Council or by the author.

Should any error be found in these codes, it would be appreciated if any relevant information be communicated to the author.

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IMPROVEMENTS TO THE AERODYNAMIC-PERFORMANCE PREDICTION FOR THE DARRIEUS WIND TURBINES

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ABSTRACT

The objective of the work described in this paper was to improve the Boeing-Vertol dynamic-stall model by considering the asymmetry of the flow between the left and right sides of the rotor. This phenomenon has been observed by flow visualization of a two-straight-bladed Darrieus rotor in the IMST water tunnel. Also introduced into the model are the effects of the blade tip and finite aspect ratio on the aerodynamic performance of the Darrieus wind turbine. These improvements are compatible with the double-multiple-streamtube model and have been included in the CARDAAV computer code for predicting the aerodynamic performance. Very good agreement has been observed between the test data (Sandia 17 m) and theoretical predictions; a significant improvement over the previous dynamic-stall model was obtained for the rotor power at low tip-speed ratios while inclusion of the finite-aspect-ratio effects enhances prediction of the rotor power for high tip-speed ratios.

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The tip losses and finite-aspect-ratio effects were also calculated for a small-scale vertical-axis wind turbine, with a two-straight-bladed (NACA 0015) rotor.

1. INTRODUCTION

The Darrieus vertical-axis wind turbine has proven to be one of the most efficient systems for wind energy conversion. Among its many advantages, mention might be made of the fact that it is omnidirectional to the wind and that most of its mechanical and electrical components (transmission, generator, etc.) are at ground level. The development of a new generation of such turbines calls for a thorough understanding of the rotor aerodynamics while selection of the best materials and suitable transmission and generator components demands an accurate evaluation not only of the rotor performance but also, in particular, of the aerodynamic forces applied to the blades. Hence the need to improve existing models in order to obtain an appropriate prediction method.

The Darrieus vertical-axis wind turbine with curved or straight blades is a fixed-pitch device and has an unsteady complex configuration. During one rotation, the flow velocity relative to the airfoil, which consists of the vector sum of the blade speed and wind speed, varies cyclically in both magnitude and direction. This variation is further modified by the presence of induced velocities, tip vortices and shed vorticity from the wakes of the blade traversing the forward half of the circular trajectory. Both the unsteady flow and the wake crossing are important factors to be considered in the estimation of the blade loading.

The major contribution to the unsteady aerodynamics of the Darrieus rotor is dynamic stall, which occurs during starting or stopping at low tip-speed ratios or in sudden gusts, and its effects have a significant role in drive-train calculations, generator sizing and overall system design. Its effects can be seen in particular on the power performance curves, which exceed the steady-flow prediction for tip-speed ratios of less than 4. The ability to predict dynamic stall is therefore of crucial importance for optimizing the Darrieus wind turbine.

No analytical model has yet been developed which is capable of predicting lift and drag in separate flow regions on the Darrieus rotor blades and so far the dynamic-stall characteristics have been approximated using the Boeing-Vertol empirical model. This stall model was developed by Gormont [1] for helicopters and is especially applicable for thin airfoils ($t/c < 12\%$) not for deep-stall ($\alpha > \alpha_{ss} + 5°$) applications.

An early modification of the Boeing-Vertol model was undertaken by Strickland [2]. Sharpe [3] later used this adaptation of the Gormont model but suggested that dynamic stall should only be considered in the calculation of the normal forces, and even then be limited to the upwind part of the rotor. Sharpe's suggestion was based on experimental results obtained at Sandia Laboratories [4].

The blade tips induce a speed which can be broken down into two components: the spanwise component, along the length of the blade, and the downwash component in the plane of the blade profile, which is perpendicular to the local relative direction of the wind. The spanwise component, which causes vertical expansion of the streamtubes, varies along the entire length of the blade: the air passing through the rotor flows towards the tips of the blades, and the streamtubes passing near the blade tips consequently gather less momentum than those passing at the equator. The reason for this is that the variation of the momentum in the direction of the X-axis has two causes: first, a change in direction towards the blade tips, known as vertical streamtube expansion and, second, transfer of momentum to the blade itself. The blade tips are consequently less efficient than the rest of the blade. To evaluate this effect, several authors [3, 5] have modified a method developed by Prandtl for propellers, based on an estimation of the radial velocity's effect of the air.

The downwash component w affects the angle of attack α and, consequently, the lift and drag coefficients, C_L and C_D respectively. A number of authors [6 - 8] use Prandtl's finite-aspect-ratio theory to account for this component of the induced speed.

2. IMPROVEMENTS TO THE DOUBLE-MULTIPLE-STREAMTUBE MODEL

2.1 Dynamic-Stall Model

Dynamic stall is a complex unsteady-flow phenomenon related to the stalling behavior of an airfoil section when the angle of attack changes rapidly with time. Several experimental studies have been done in this field, especially for helicopter applications [9, 10] and shown that the loads of an airfoil oscillating harmonically in pitch are different from those of a nonpitching airfoil at the same angle of attack.

In the case of the Darrieus wind turbine, when the operational wind speed approaches its maximum, all blade sections exceed the static-stall angle, the angle of attack changes rapidly, and the whole blade works in dynamic-stall conditions. In this analysis, we used the Boeing-Vertol dynamic-stall model [1] as modified by Strickland [2], which assumes that the lift-curve slope and zero-lift angle remain unchanged and that dynamic effects only modify the angle of attack at which stall occurs. Thus a modified angle of attack is utilized for entering two-dimensional force-coefficient data. The modified angle of attack α_m is a function of $c\dot{\alpha}_b/(2W)$ and other parameters (α_b, γ, and K_1) and is given by the relation

$$\alpha_m = \alpha_b - \gamma K_1 \left(\left| \frac{c\dot{\alpha}_b}{2W} \right| \right)^{\frac{1}{2}} S_{\dot{\alpha}} \tag{1}$$

where W represents the relative inflow velocity, α_b is the effective blade angle of attack, γ and K_1 are empirical constants; $\dot{\alpha}_b$ represents the instantaneous rate of change of α_b, and $S_{\dot{\alpha}}$ is the sign of $\dot{\alpha}$.

The instantaneous coefficients of lift, moment and drag are given respectively by

$$C_L = \left(\frac{\alpha_b}{\alpha_m - \alpha_{b0}} \right) C_L(\alpha_m) \tag{2}$$

$$C_M = C_M(\alpha_m) \tag{3}$$

$$C_D = C_D(\alpha_m) \tag{4}$$

where α_{b0} is the effective blade angle of attack for zero lift. The values of γ are functions of the airfoil thickness-to-chord ratios (t/c) and the local blade Mach number. For $t/c > 0.10$ and low Mach numbers, the values of γ_L for lift stall, γ_M for moment stall, and γ_D for drag stall are

$$\gamma_L = 1.4 - 6(0.06 - t/c) \tag{5}$$

$$\gamma_M = 1 - 2.5(0.06 - t/c) \quad (6)$$

$$\gamma_D = \gamma_M \quad (7)$$

The K_1 values change with the sign of the effective angle of attack and are calculated by

$$K_1 = 0.75 + 0.25 S_{\dot{\alpha}} \quad (8)$$

The angle of attack as calculated by the double-multiple-streamtube model does not take account of the turbulence of the flow. However, water tunnel observations at the French institute IMST [12] show that several levels of turbulence do in fact exist in each quadrant as well as asymmetry between the left and right sides of the rotor compared to undisturbed flow. This is illustrated schematically in Figure 1, where the larger parts of quadrants I and II are crossed by a very turbulent flow. Since turbulence delays the dynamic stall [13] it is preferable not to take this phenomenon into account in highly turbulent zones. Rather, the double-multiple-streamtube model uses the static-stall angle (constant for one entire cycle) to estimate the dynamic-stall angle which varies with the level of turbulence. Analysis of Figure 1 reveals a zone of low turbulence between the azimuthal angles of 135° to 15°, i.e. quadrants III, IV and part of quadrants I and II. For better computational accuracy, the dynamic-stall model is therefore used only in the low-turbulence zone.

2.2 Blade-Tip and Finite-Aspect-Ratio Effects

The proposed model can be applied at two stages in the calculation: first, to compute the interference factors, u and u' (momentum theory) and second, to determine the angle of attack α and the lift and drag coefficients C_L and C_D (blade-element theory). Unlike existing counterparts, the proposed model takes account of the two components of the tip speed, namely the spanwise component, which in turn has two levels of intervention, and the downwash component, which affects mainly the blade element theory.

The effects of the spanwise component are included with the aid of Willmer's modified version [5] of the Prandtl method developed for screw propellers. This is justifiable because the multiple-streamtube method is based on the Prandtl-Betz disk theory and assumption that $V = \frac{1}{2}(V_\infty + V')$ both of which are propeller-related principles. The method consists in replacing the propeller wake by a series of flat disks separated by a distance, s. This allows a factor F to be calculated which corresponds to a momentum-transfer-reduction factor for each streamtube [14]. The principle underlying the multiple-streamtube model and the rotor geometry are depicted in Figure 2.

For a given streamtube, we have

$$F(a,s) = \frac{\operatorname{arcos}(e^{-\frac{\pi a}{s}})}{\operatorname{arcos}(e^{-\frac{\pi H}{s}})} \qquad (9)$$

$$s = \frac{\pi V_e}{N\omega} \quad \text{upwind zone}$$

$$s = \frac{\pi V''}{N\omega} \quad \text{downwind zone}$$

$$a = H - |Z|$$

This reduction in the momemtum transfer is due to the slope of the induced velocity (V or V', Figure 2) versus the blade span. Since this is equavalent to the slope of the blade, it suffices to use the two formulas [11] below to take account of this effect:

$$W^2 = V^2[(X - \sin\theta)^2 + F^2\cos^2\theta\cos^2\delta] \qquad (10)$$

for the relative velocity, and

$$\alpha = \frac{F\cos\theta\cos\delta}{[(X - \sin\theta)^2 + F\cos^2\theta^2\cos^2\delta]^{\frac{1}{2}}} \qquad (11)$$

for the angle of attack.

For the case of a straight-bladed wind turbine, $\delta = 0$.

The effects of the downwash component are included simply by applying Prandtl's finite-aspect-ratio theory.

Assuming an elliptical distribution of the flow over a blade, two equations [15] are obtained which allow the characteristics of the blade profile (indexed ∞) to be converted into the characteristics of a finite-length blade (indexed f)

$$C_{Lf} = C_{L\infty}/(1 + a_0/\pi\ AR) \tag{12}$$

$$C_{Df} = C_{D\infty} + C_{Di} \tag{13}$$

where $C_{Di} = C_{Lf}{}^2/\pi\ AR$

$AR = l^2/S$, with l representing the span length and S the surface of the plane projection of the blade. For a rectangular blade, $AR = l/c$.

$$a_0 = 1.8\ \pi\ (1 + 0.8\ t/c)$$

With the presence of downwash w, the effective angle of attack α_e becomes

$$\alpha_e = \alpha - \alpha_i \tag{14}$$

$$\alpha i = CLf/\pi\ AR$$

Since equations (12), (13), and (14) are derived from linear theory, they do not apply to dynamic-stall calculations.

3. RESULTS AND DISCUSSION

The effects of stall are very visible on the curves of the power P versus the wind speed at the equator, V_{EQ}. In order to illustrate the improvements to the dynamic-stall model, the curve of Figure 3 was plotted for the Sandia 17-m wind turbine at 42.2 RPM. The first feature to be noted is that in the improved dynamic-stall model the curve reaches a plateau, which corresponds to Sandia's experimental results. This represents a distinct improvement over the results obtained with the earlier model [1] which had no plateau. Closer study of Figure 3 reveals that both the improved model and the Gormont model predict a later stall than that suggested by experimental data, according to which stall appears at V_{EQ} = 11 m/s; the CARDAAV calculations give 12 m/s. The reason for this is that the calculated angles of attack were underestimated. It should be pointed out that the improvements to the model do not change the wind speed at which stall begins. The improved model predicts more marked effects than the experimental results: the calculations indicate an abrupt change in slope whereas a gradual change in slope is identified between the linear domain and the plateau according to the experimental results. Figure 4 shows the curve of the power coefficient C_p plotted versus the tip-speed ratio X_{EQ}, which shows a distinct improvement in the computational accuracy for low tip speeds, although no difference is noted in the estimated maximum power coefficient C_{pmax}.

The influence of the blade tips was calculated for a two-straight-bladed rotor 6 m high with a radius of 3 m. A NACA 0015 blade profile and chord of 0.2 m were used. The rotational speed was 125 RPM.

In order to illustrate the effects of the blade tip and the finite aspect ratio, a distinction was made between the two induced-velocity components. Considering the first of these, the spanwise component, Figure 5 shows that it varies in intensity along the length of the blade as a result of variations in the upstream and downstream interference factors, $u = V/V_\infty$ and $u' = V'/V_e$ [11] respectively. It can be seen that these interference factors increase at the blade tips, resulting in a power loss. The figure leaves no doubt that the blade tips are less efficient than the part of the blade located at the equator. It is also clear that the spanwise component is zero at the equator and therefore has no effect at that level. A symmetrical variation can be noted in the interference factor with respect to the equator, owing to the fact that no account was taken of the atmospheric boundary layer in this calculation. Obviously, if the latter were considered, dissymmetry with respect to the equator would be obtained.

The effects of the downwash component are especially noticeable on the lift and drag coefficients. Figure 6 illustrates the decrease in the lift coefficient. This curve was plotted for a complete rotation at the level of the equator ($X_{EQ} = 5.20$) where, as mentioned above, the influence of the spanwise component is zero. A slight decrease in the lift coefficient can be observed, mainly for wide angles of attack corresponding to θ values of 0° and 180° (Figure 2). The influence of the downwash component is stronger on the drag coefficient which, as illustrated in Figure 7, shows a substantial increase.

The combined effects of the two induced components (increased interference factor and drag, decreased lift) result in a strong reduction in the tangential force (Figure 8), causing a power loss (Figure 9). The downward slope can be seen in the linear domain and the plateau of the dynamic stall is significantly lower. The example given in the latter figure shows that for a velocity of 14 m/s the power loss will be as much as 10%. It can be seen too that the higher the wind speed, the greater the loss. The curve in Figure 10 illustrates the drop in the power coefficient C_p. A large decrease is noted in C_{pmax} (25%), although this coefficient occurs at the same tip-speed ratio. The observed effects obviously take on great importance in the design of wind turbine transmission and generator components. Better evaluation of the power also allows a better estimation of the mean annual potential of the machine. From the point of view of structural calculation, the blade tips and finite aspect ratios can be seen to have far less influence, as illustrated in Figure 11 where the normal force is only slightly reduced.

Figures 12 and 13 show the extent of the blade-tip effects for three finite aspect ratios: 10, 20 and 30. Coefficients K_p and C_p decrease as the ratio increases, C_p in particular, which for a AR of 10 shows a

60% loss. Normally, the blades of a wind turbine have a finite aspect ratio of about 30, for which K_{pmax} shows a loss of 10% and C_{pmax} a decrease of as much as 20%. The curve of C_p shows very clearly the influence of the finite-aspect ratio, hence the need for solutions to reduce its effect. It should be pointed out that if the finite-aspect-ratio effects were not included, the three lower curves in Figures 12 and 13 would not be distinguishable from the curve that neglects the blade-tip effects.

4. CONCLUSION

The finite-aspect-ratio effects combined with recent improvements to the dynamic-stall model were introduced for calculating the power of the Sandia 17-m wind turbine. The results obtained for three rotational speeds (42.2, 46.7 and 50.6 RPM) provide a good estimation of the real power (Figures 14 to 16). For high tip-speed ratios (pre-stall) better computational accuracy is obtained if the finite-aspect-ratio effects are included while a good estimate of the power is obtained for low tip-speed ratios by the improvements to the dynamic-stall model. On the other hand, no improvement was achieved which solved the convergence problem encountered at high tip-speed-ratios.

The proposed stall model shows a virtually identical performance for the three rotational speeds (see Figures 14 to 16), predicting a late stall. Moreover the curve always has the same shape, i.e. a linear part and a plateau and bears a strong similarity to the experimental curves of Figures 14 and 15. However, the experimental curve in Figure 16 has no plateau, the power continues to increase, albeit at a slower rate. On the other hand, at 50.6 rpm the model still predicts a plateau in the dynamic-stall zone.

ACKNOWLEDGMENT

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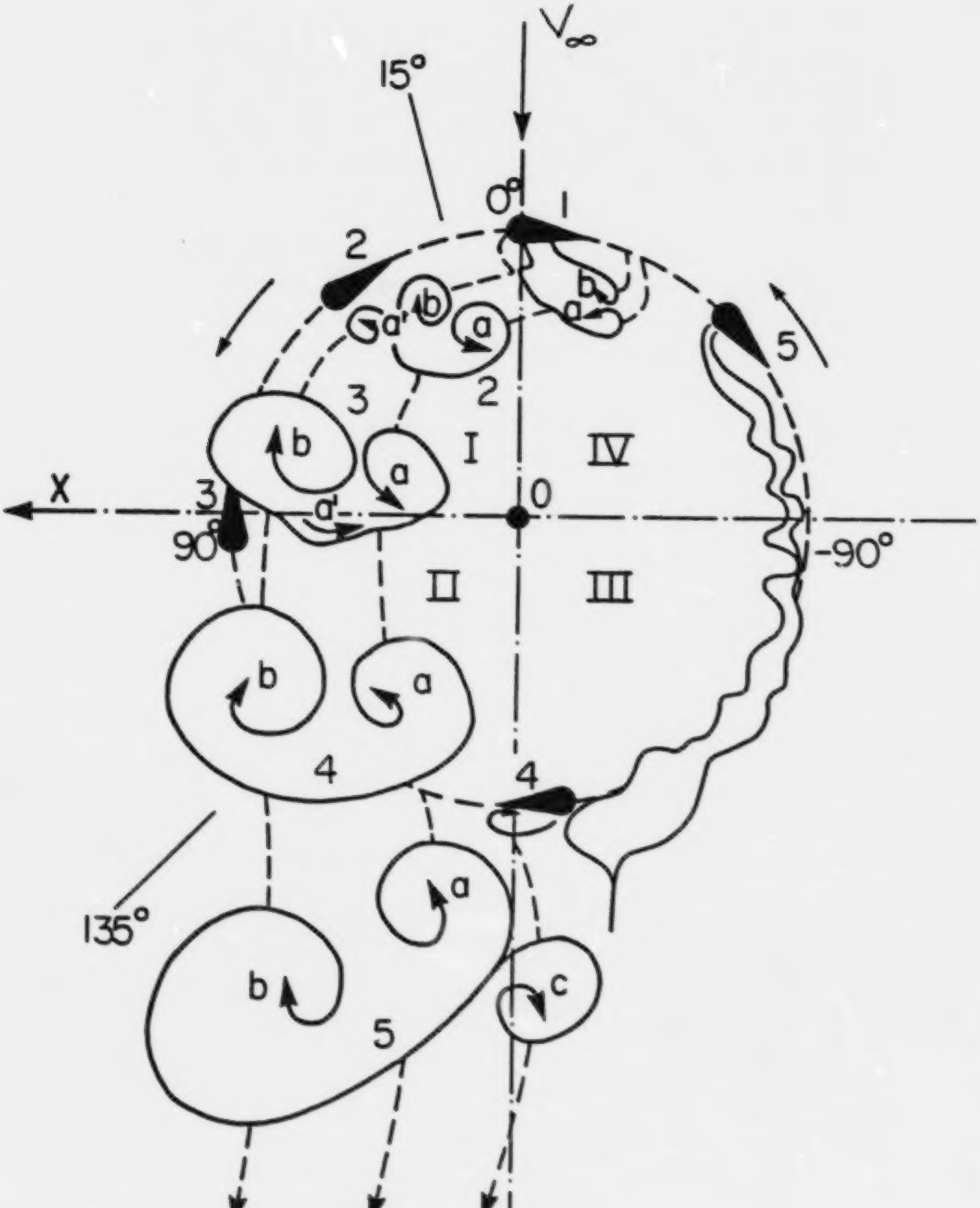
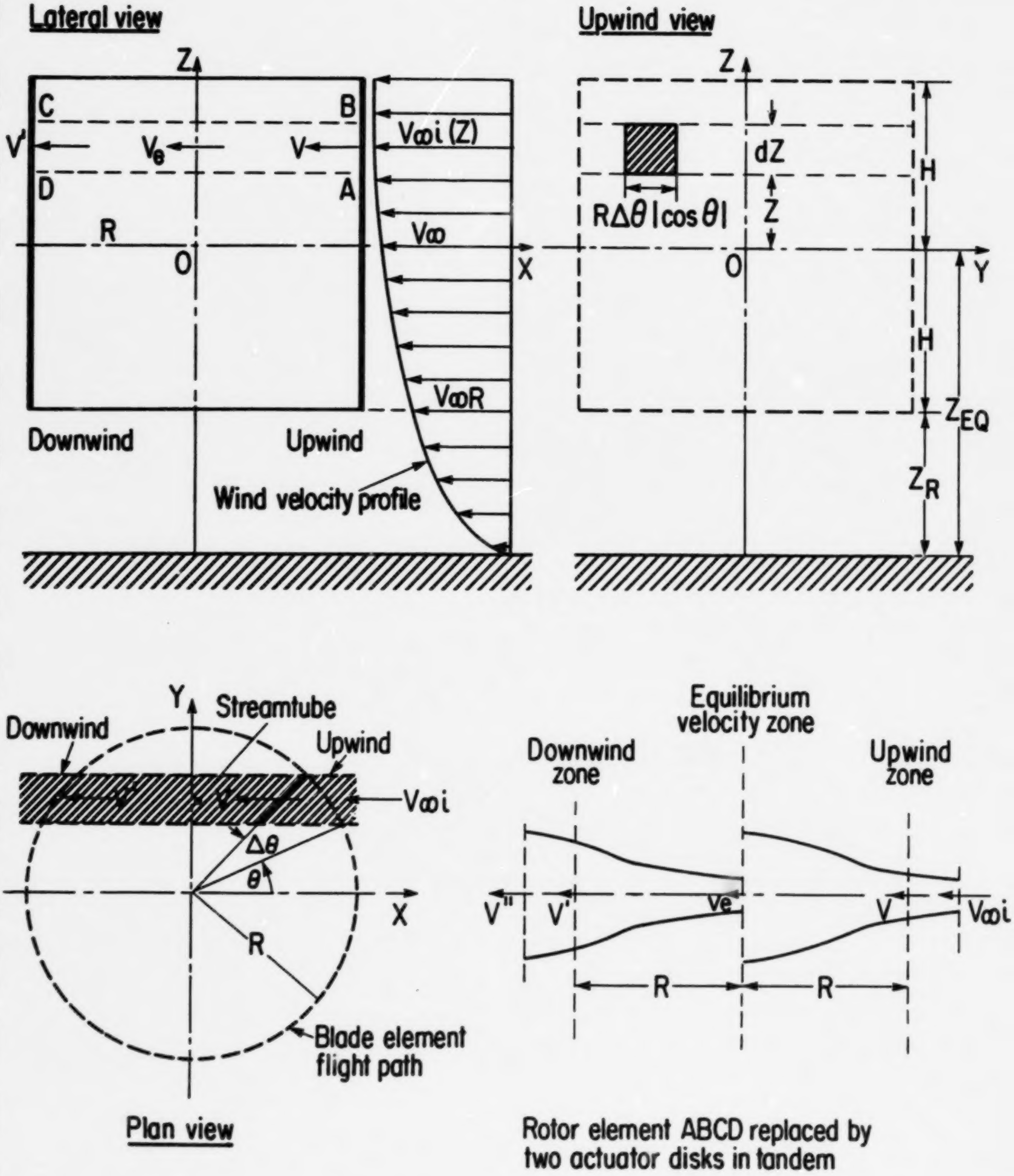

V∞
15°
0°
1
2
b
a'
b
a
a
5
3
2
b
a
I
IV
X
3
0
a'
90°
-90°
II
III
b
a
4
4
a
135°
b
c
5
Y

Fig. 1



Lateral view

Upwind view

Plan view

Rotor element ABCD replaced by two actuator disks in tandem

Z
C
B
V'
V_e
V
D
A
R
O
X
$V_{\infty i}(Z)$
V_∞
$V_{\infty R}$
Downwind
Upwind
Wind velocity profile
Z
dZ
$R\Delta\theta|\cos\theta|$
Z
H
H
O
Y
Z_{EQ}
Z_R
Y
Streamtube
Downwind
Upwind
V''
V'
$V_{\infty i}$
$\Delta\theta$
θ
X
R
Blade element flight path
Equilibrium velocity zone
Downwind zone
Upwind zone
V''
V'
Ve
V
$V_{\infty i}$
R
R

Fig. 2

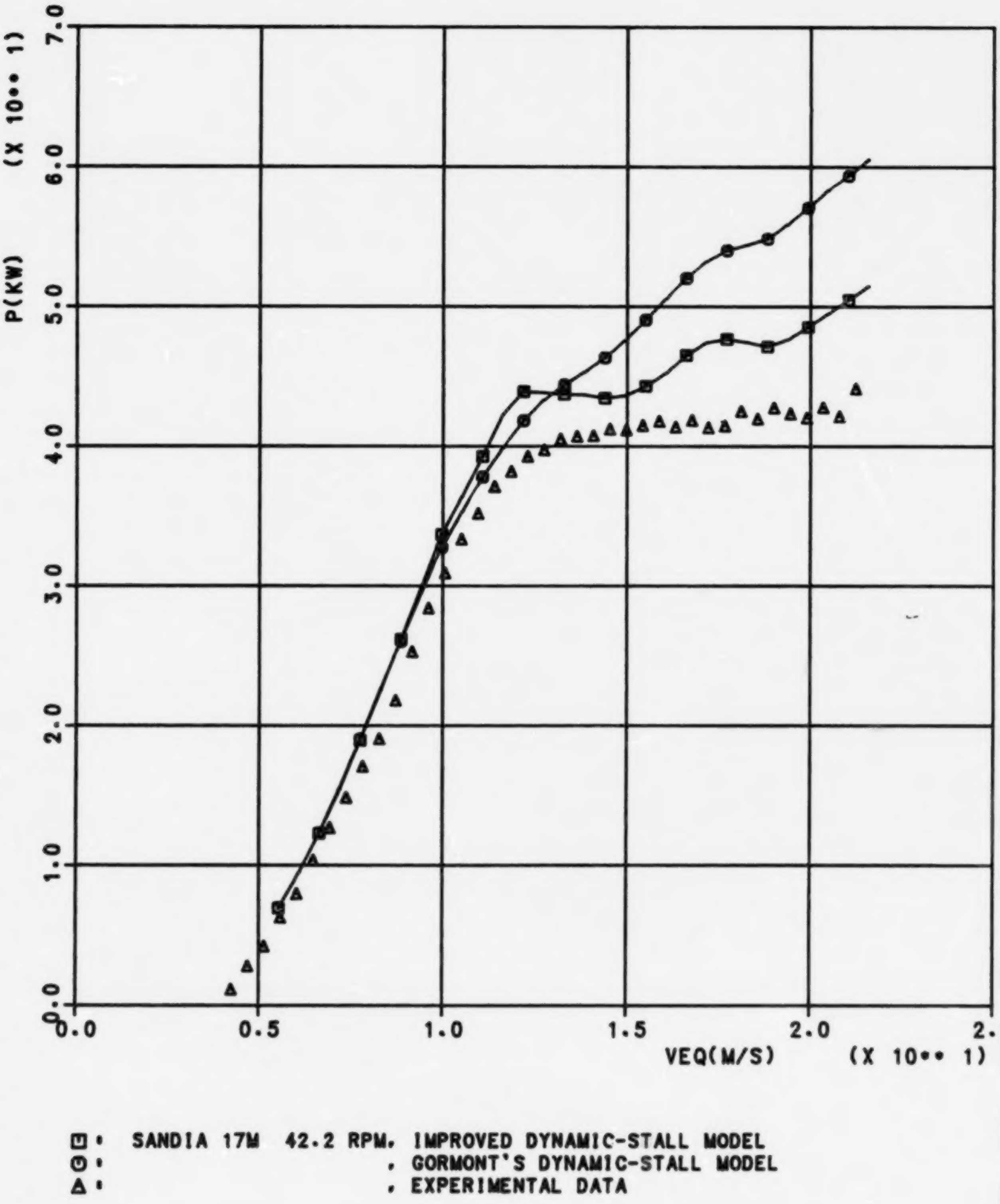

P(KW) (X 10** 1)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
VEQ(M/S) (X 10** 1)
0.0
0.5
1.0
1.5
2.0
2.5
⊡ : SANDIA 17M 42.2 RPM, IMPROVED DYNAMIC-STALL MODEL
⊙ : , GORMONT'S DYNAMIC-STALL MODEL
Δ : , EXPERIMENTAL DATA

Fig. 3

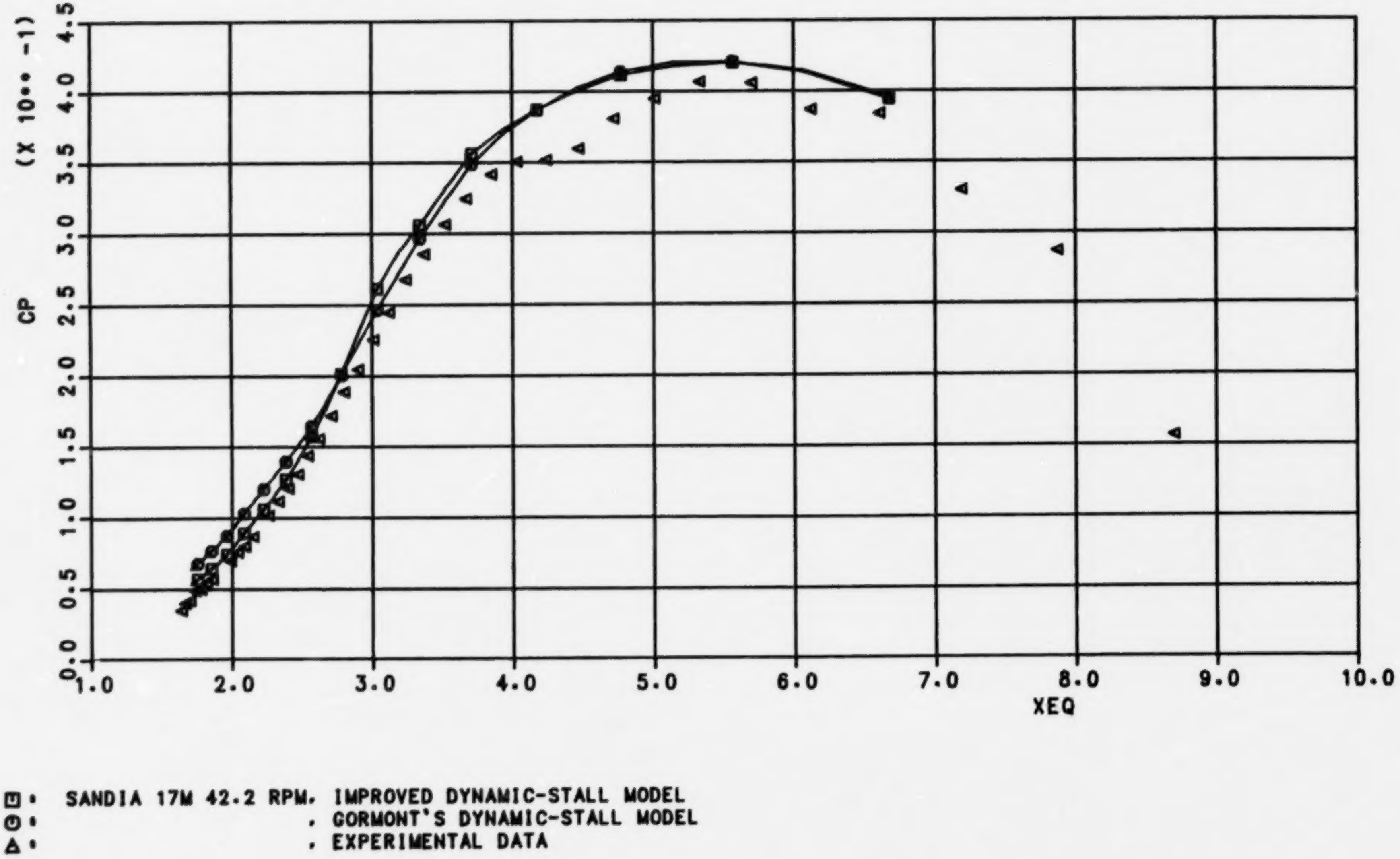
CP
(X 10** -1)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
XEQ
⊡: SANDIA 17M 42.2 RPM. IMPROVED DYNAMIC-STALL MODEL
⊙: , GORMONT'S DYNAMIC-STALL MODEL
△: , EXPERIMENTAL DATA

Fig. 4

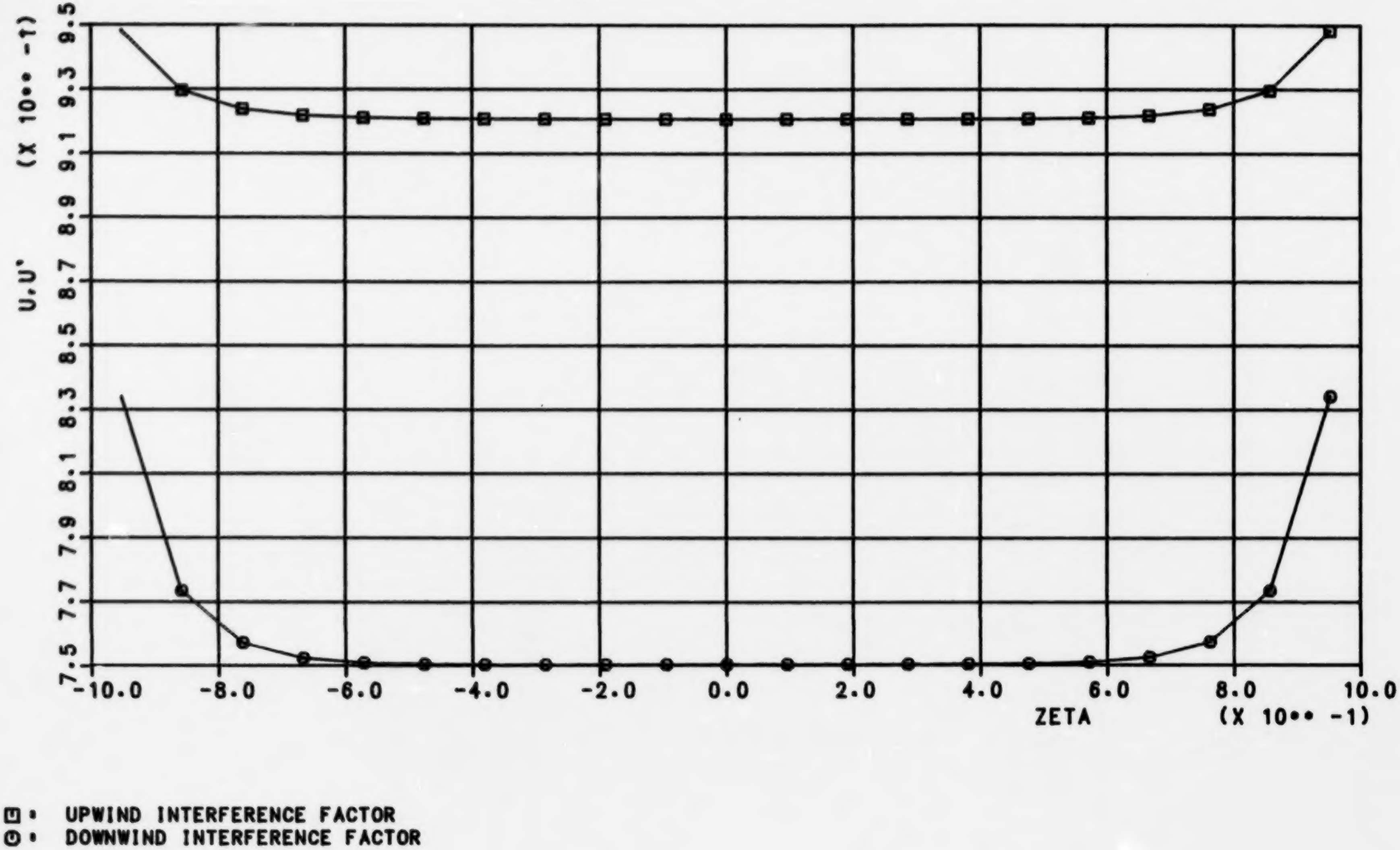

U,U'
(X 10** -1)
9.5
9.3
9.1
8.9
8.7
8.5
8.3
8.1
7.9
7.7
7.5
-10.0
-8.0
-6.0
-4.0
-2.0
0.0
2.0
4.0
6.0
8.0
10.0
ZETA
(X 10** -1)
□: UPWIND INTERFERENCE FACTOR
⊙: DOWNWIND INTERFERENCE FACTOR

Fig. 5

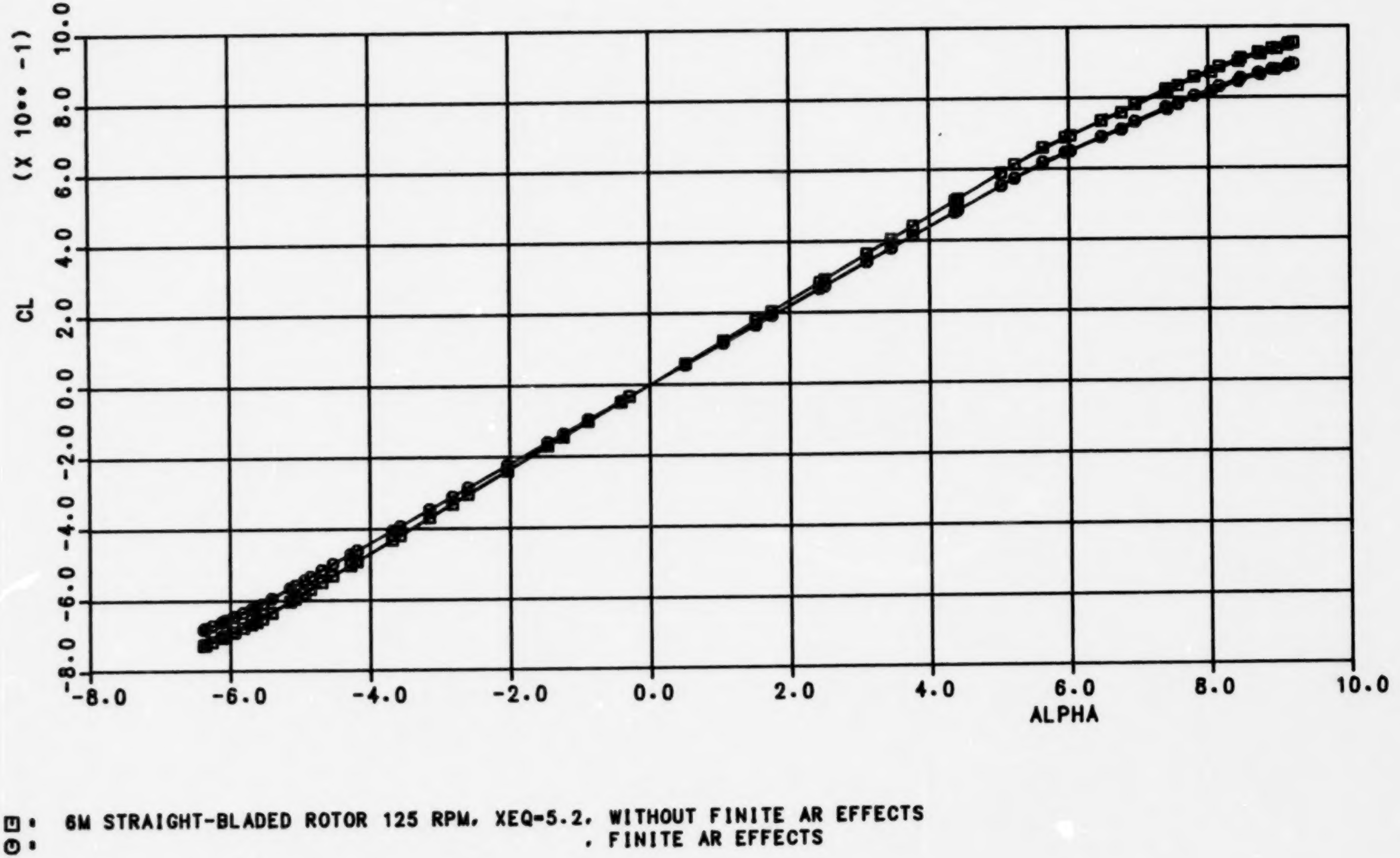
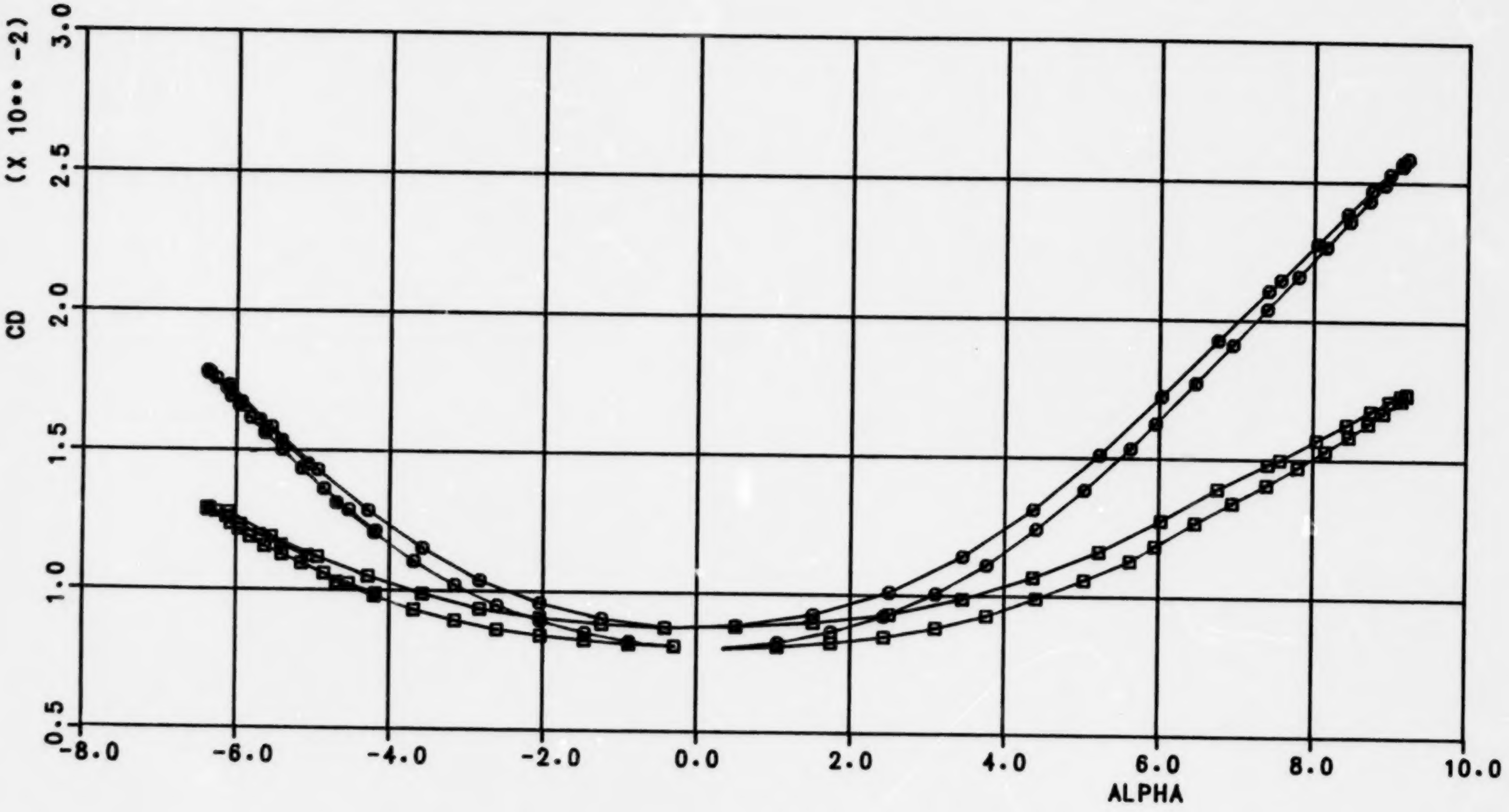

CL
(X 10** -1)
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-8.0
-6.0
-4.0
-2.0
0.0
2.0
4.0
6.0
8.0
10.0
ALPHA
⊡ : 6M STRAIGHT-BLADED ROTOR 125 RPM, XEQ=5.2, WITHOUT FINITE AR EFFECTS
⊙ : , FINITE AR EFFECTS

Fig. 6



⊡: 6M STRAIGHT-BLADED ROTOR 125 RPM, XEQ=5.2, WITHOUT FINITE AR EFFECTS
⊙: , FINITE AR EFFECTS

Fig. 7

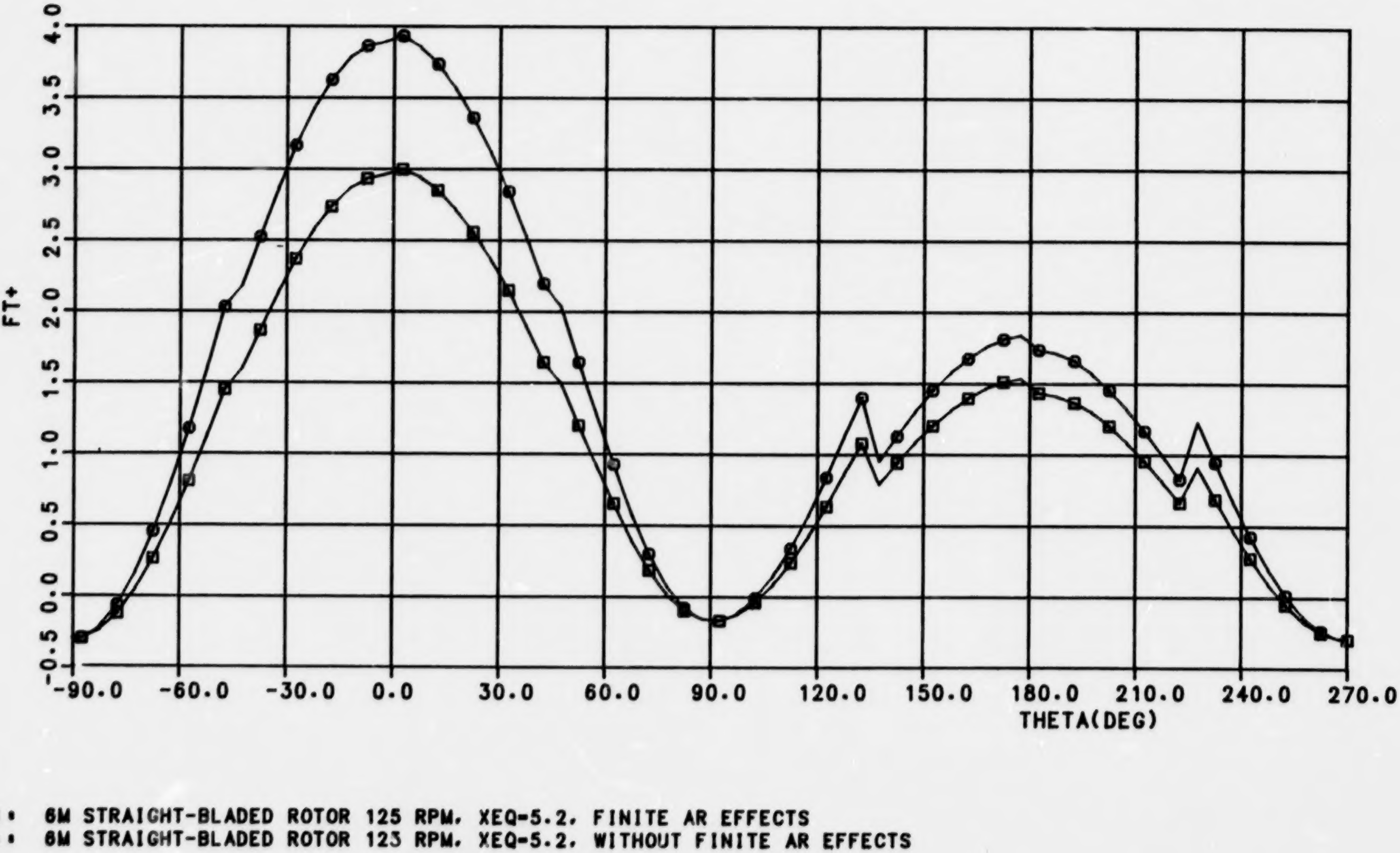
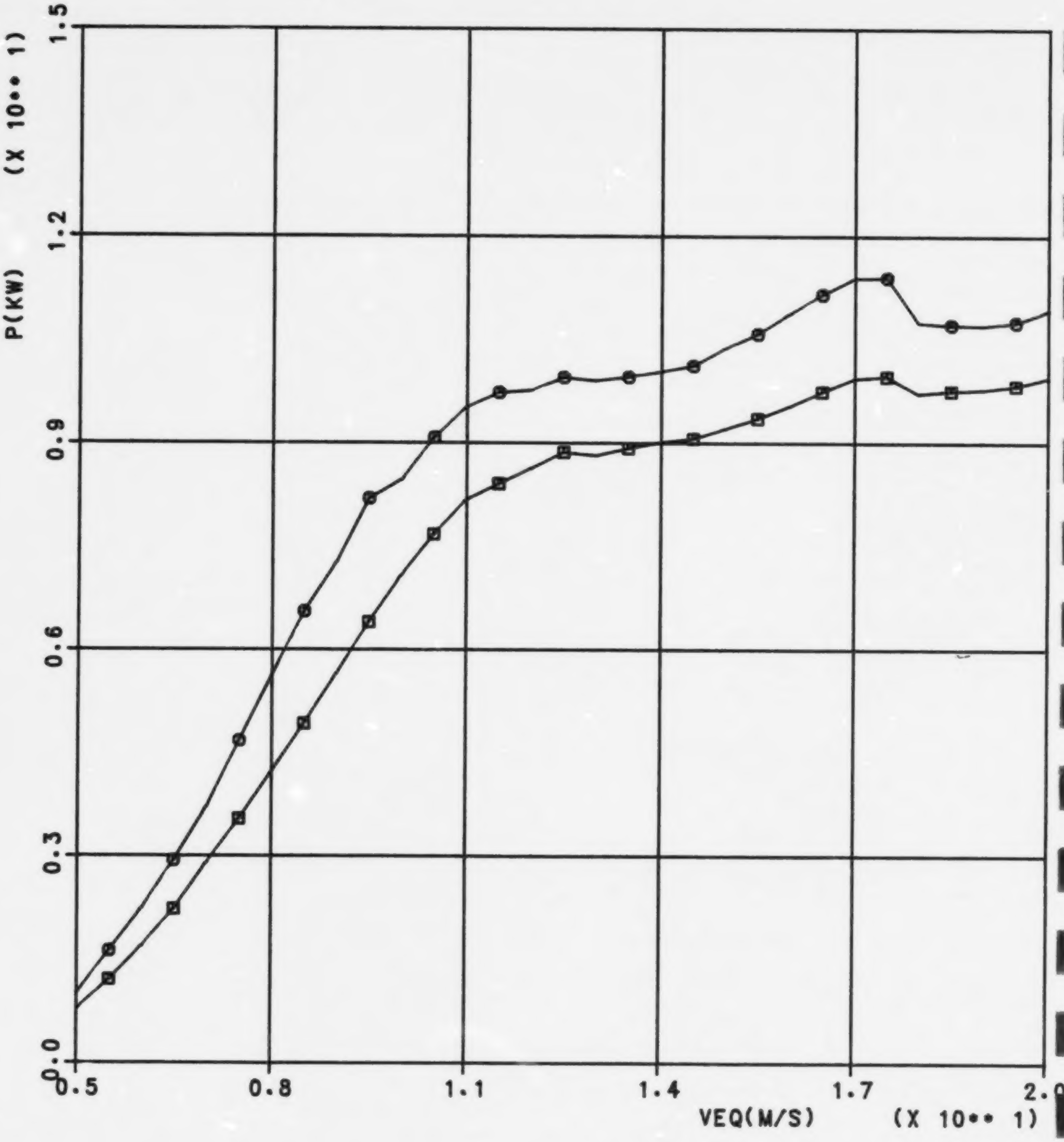

FT+
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-90.0
-60.0
-30.0
0.0
30.0
60.0
90.0
120.0
150.0
180.0
210.0
240.0
270.0
THETA(DEG)
⊡ : 6M STRAIGHT-BLADED ROTOR 125 RPM, XEQ=5.2, FINITE AR EFFECTS
⊙ : 6M STRAIGHT-BLADED ROTOR 123 RPM, XEQ=5.2, WITHOUT FINITE AR EFFECTS

Fig. 8



□ : 6M STRAIGHT-BLADED ROTOR 125 RPM, FINITE AR EFFECTS
○ : , WITHOUT FINITE AR EFFECTS

Fig. 9

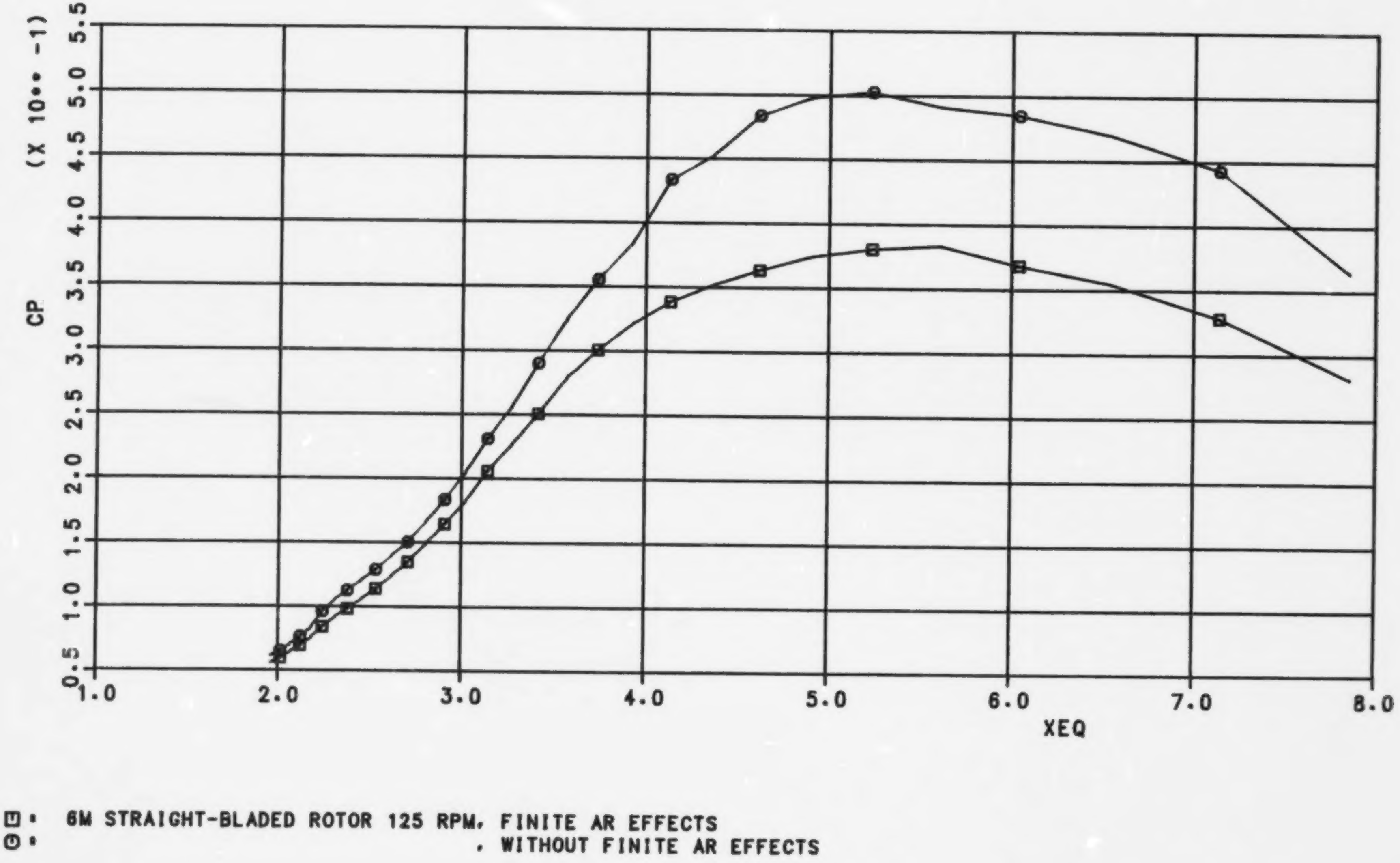

CP
(X 10** -1)
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
XEQ
⊡ : 6M STRAIGHT-BLADED ROTOR 125 RPM, FINITE AR EFFECTS
⊙ : , WITHOUT FINITE AR EFFECTS

Fig. 10

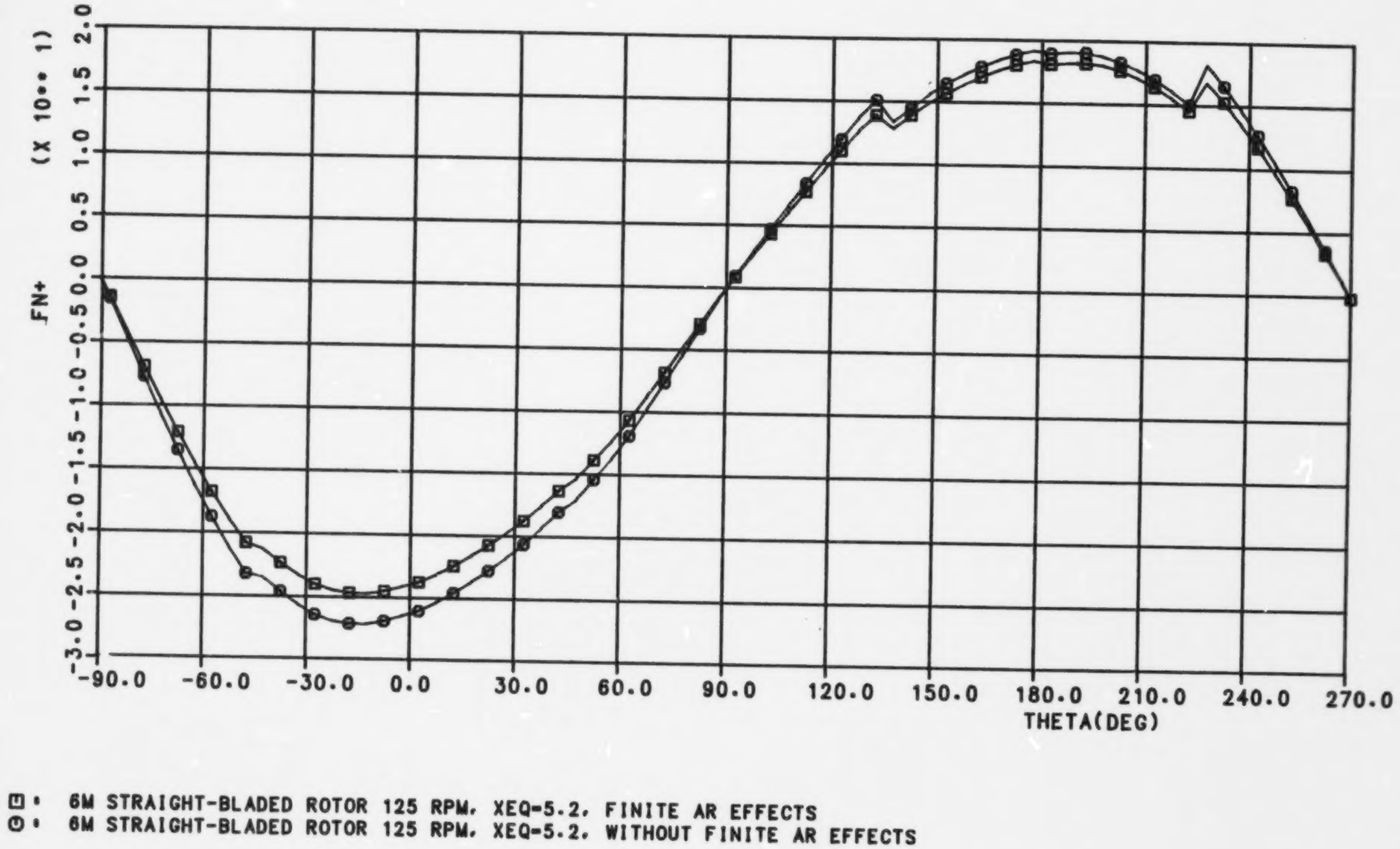

(X 10** 1)
FN+
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-90.0
-60.0
-30.0
0.0
30.0
60.0
90.0
120.0
150.0
180.0
210.0
240.0
270.0
THETA(DEG)
⊡ : 6M STRAIGHT-BLADED ROTOR 125 RPM. XEQ=5.2. FINITE AR EFFECTS
⊙ : 6M STRAIGHT-BLADED ROTOR 125 RPM. XEQ=5.2. WITHOUT FINITE AR EFFECTS

Fig. 11

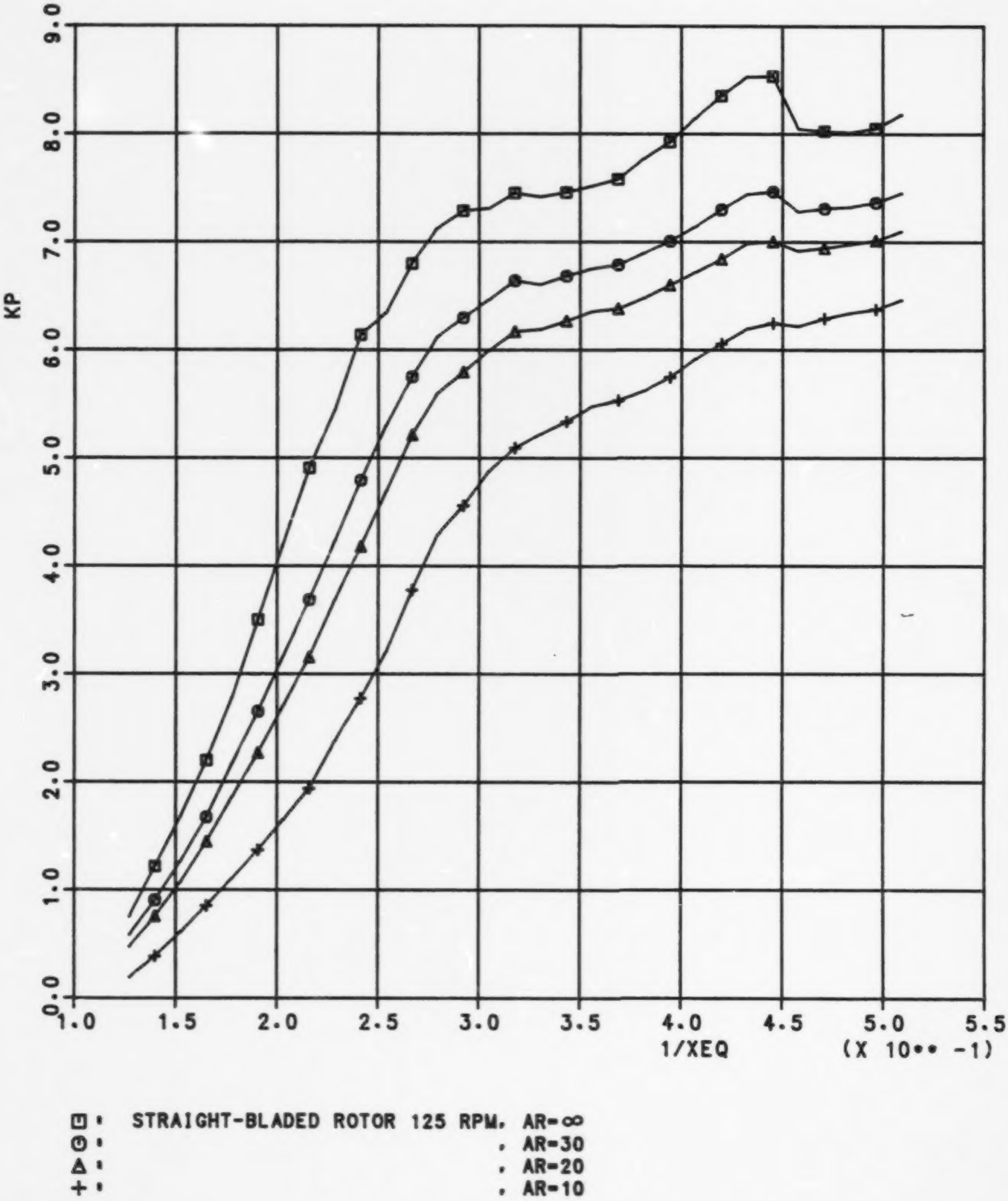

KP
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
1/XEQ
(X 10** -1)
⊡ : STRAIGHT-BLADED ROTOR 125 RPM, AR=∞
⊙ : , AR=30
△ : , AR=20
+ : , AR=10

Fig. 12

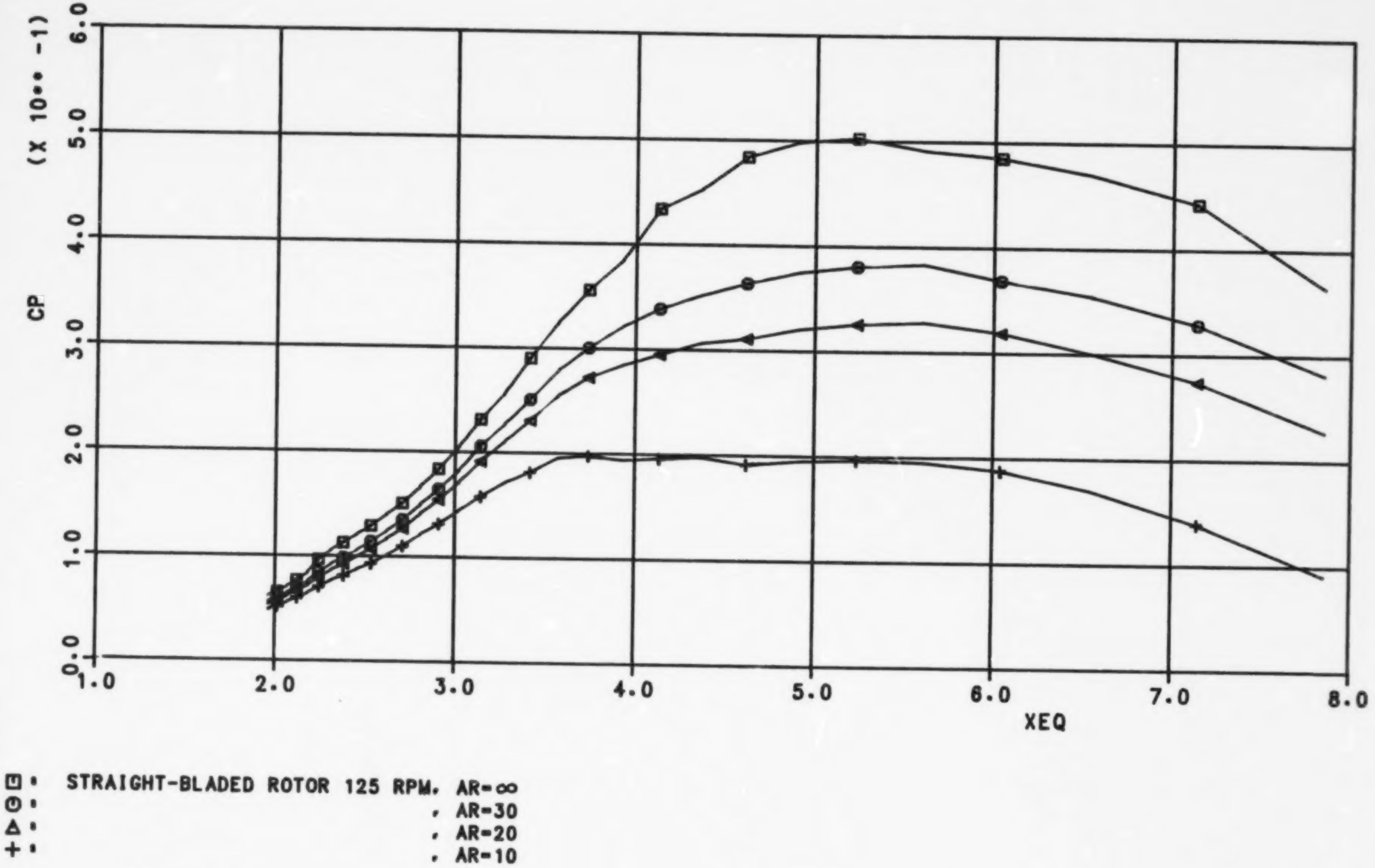
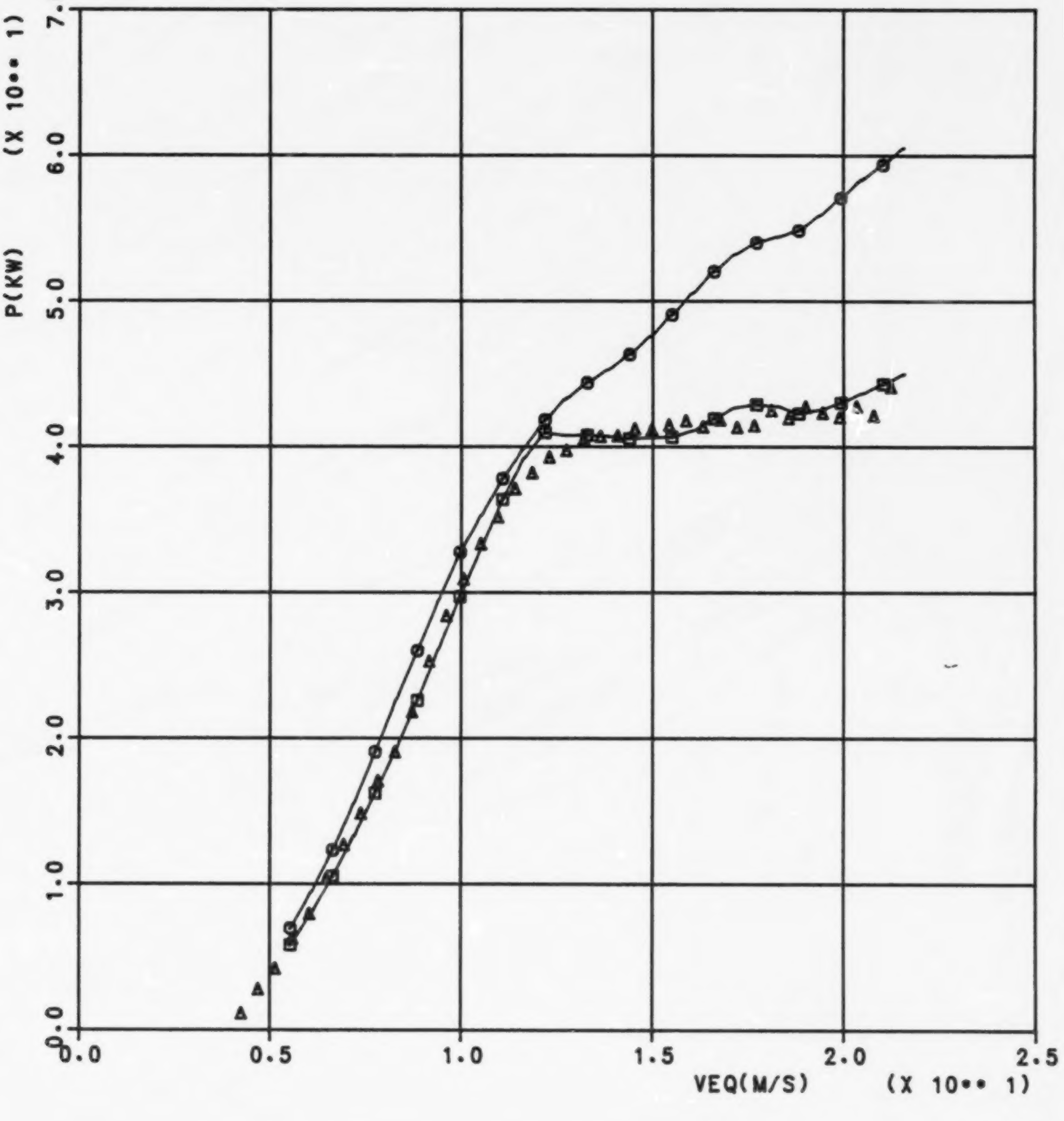
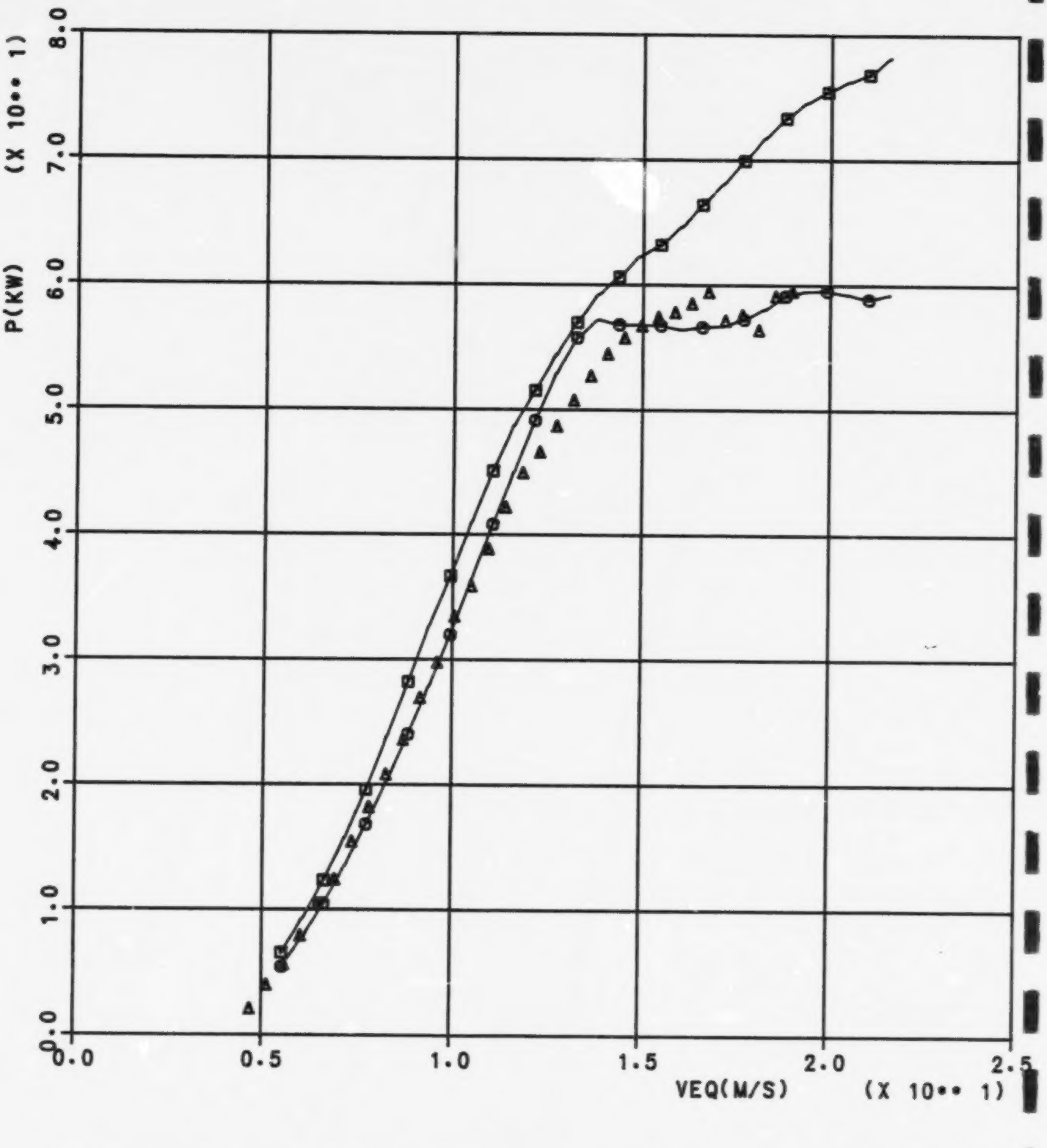

(X 10** -1)
CP
0.0
1.0
2.0
3.0
4.0
5.0
6.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
XEQ
□ : STRAIGHT-BLADED ROTOR 125 RPM, AR=∞
⊙ : , AR=30
△ : , AR=20
+ : , AR=10

Fig. 13



□ : SANDIA 17M 42.2 RPM, IMPROVED DYNAMIC-STALL MODEL & FINITE AR EFFECTS
⊙ : , GORMONT'S DYNAMIC-STALL MODEL
△ : , EXPERIMENTAL DATA

Fig. 14



□ : SANDIA 17M 46.7 RPM, IMPROVED DYNAMIC-STALL MODEL & FINITE AR EFFECT
⊙ : , GORMONT'S DYNAMIC-STALL MODEL
△ : , EXPERIMENTAL DATA

Fig. 15

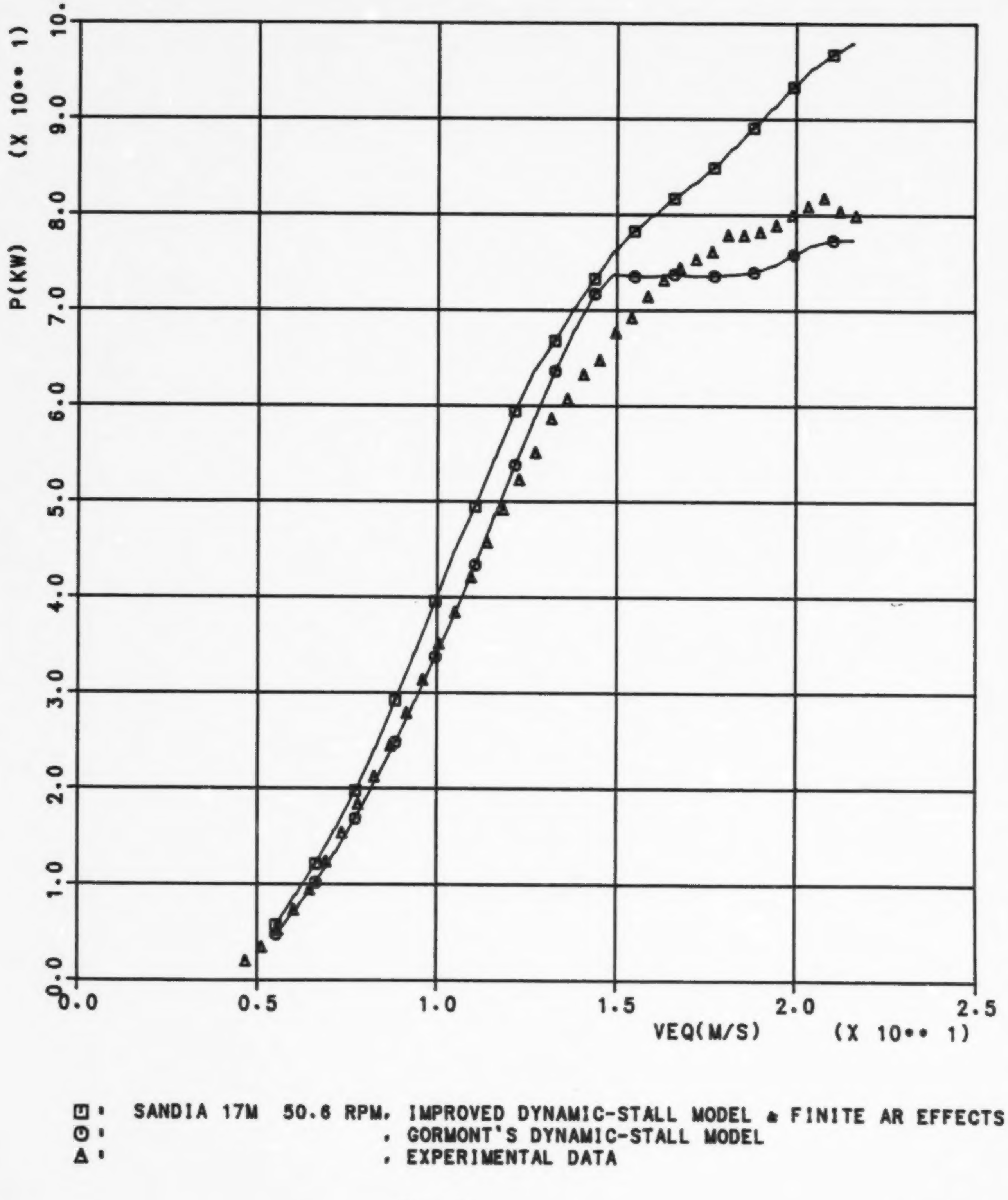

P(KW) (X 10** 1)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
0.0
0.5
1.0
1.5
2.0
2.5
VEQ(M/S) (X 10** 1)
□ : SANDIA 17M 50.6 RPM, IMPROVED DYNAMIC-STALL MODEL & FINITE AR EFFECTS
⊙ : , GORMONT'S DYNAMIC-STALL MODEL
Δ : , EXPERIMENTAL DATA

Fig. 16

ECONOMIC AND LEGAL ISSUES

WIND POWER
An Overview of Canadian Experience

By DAVID HOFFMAN
World Wind Communications Co.

For presentation at the
Canadian Wind Energy Association Conference
Ottawa, December 9-10, 1985

0. INTRODUCTION

Compared to wind power industries in the United States, Denmark and the Netherlands, Canada's wind power industry ranks in the small category, like the industries of the U.K., West Germany, France, Italy or China.

Since Canada appears to have a fairly large potential market for wind generators and water pumpers, it is fair for our industry to expect to grow into that market. This is especially true for wind generators at isolated, windy locations where diesel-fired power plants are presently in use.

Like other energy technologies, wind turbines do not operate in an economic vacuum. The cost of energy from wind power is meaningless unless measured against the cost of other energy sources in any given application.

Where wind power differs from, for example, coal-fired electricity, is that farmers, homeowners and other energy consumers tend not to buy coal-fired power plants, but when in a windy region, are in a position to buy a wind turbine. Hence, government involvement in the development and use of wind power has a travelled a different path than their involvement in exclusively utility-scale energy technologies.

Industry representatives who participated in Energy, Mines and Resources' renewable energy consultation workshop, recently held at the Montebello resort, now know that EMR is preparing its national R&D program for this broad sector. Hence, this time is a good opportunity to examine some of our past experiences with government involvement, to take advantage of hindsight and apply our limited resources efficiently and practically without repeating mistakes or relearning past lessons all over again.

1. TECHNOLOGY DEMONSTRATION

Other speakers at this conference will provide details on various projects I would call research, concerning the testing and performance of prototypes made possible by National Research Council funding, and the development of their various components and systems.

I'd like to describe our experience in the demonstration projets which have been funded by federal and provincial governments alike since the late 1970's. I'd also like to talk about a form of government participation Canada's wind power industry hasn't really seen yet, except by exclusion, which is namely market intervention in our mixed economy.

I should mention I'm a little nervous about being up here, and I hope you'll bear with me and see past my oratory inexperience. Feel free to boo if it helps you stay awake.

By our definition, a demonstration project serves to encourage the use of wind systems by the government providing a financial contribution to install, operate and monitor such systems, then document this experience and publicize it to members of the public, industry or government who could benefit from using wind turbines to serve their energy requirements.

Such activities were intended under the various conservation and renewable energy demonstration agreements signed by Ottawa, the provinces and the territories about five years ago. A number of provinces also operated their own small-scale pilot project programs, serving basically the same ends and also receiving federal funding. Typically, these programs funded 50 per cent or more of the cost of each given project and actually, the resulting number of wind system installations is rather impressive.

In total, at least 53 wind generators were erected, totalling about 160 kilowatts of generating capacity. The largest were under 20 kW capacity and the smallest, under 500 watts. Government funding covered about 1.5 to 3 dollars per installed watt if you take project budgets as they appear on the surface. Applications consisted of residential, commercial and institutional electricity supply in stand-alone operation, connected to provincial utility networks or connected to diesel-fired networks in remote regions. About half of them are battery-chargers and the rest mostly connected to the provincial grids.

Unfortunately, the programs funding these installations have not successfully led to further installations. Nor have they been successful at compiling field experience at a central location in an accessable form. About the only documentation produced on most of these projects consisted of a one-page factsheet giving the barest of details and often misinterpreting specific project costs. Somewhat more thorough reports were published, but having been produced shortly after the wind systems in question were installed, lack meaningful operational experience. Performance monitoring was nonexistant in most of the 53 projects and one may only guess how many are still operating.

If that implies the reliability of these machines is doubtful, one must be provided with something to compare it with, and here we get into another problems these demonstration programs did not address. In fact, they did quite the opposite, but a comparison with experience in other countries must be made to understand what that really means.

2. FOREIGN EXPERIENCE

Essentially every country considered today to possess a meaningful market for wind generators, is that way because the government there provides one or another form of market incentive to encourage installations.

Most familiar are the American tax credits on the purchase of renewable energy technologies and the related, equitable regulations toward electric utility purchases of independently-generated power. Less well known on this side of the Atlantic are similar incentives and regulations in Denmark and the Netherlands. In the U.K., the situation is rather reversed, which is a polite way of saying backwards, and actually alot like Canada. The difference between Danish and British wind power industries is that Danish machines are also installed in Denmark and not just exported.

Many consider Danish wind generators to be at the top of the reliability heap, but they didn't get that way just because their government provides market incentives. It's the way these incentives are awarded, in combination with a procedure to to ensure the technology is reliable before being put to commercial use. Here, I refer to the establishment of a national wind system test facility not unlike our own center in Prince Edward Island.

Up until this year, the Danish government paid for the testing of wind turbines at the test facility, which private industry was required to submit to in order to receive a licence. This, in turn, makes the turbine model eligible for utility connection, the tax credit and easier zoning approval.

The benefits of the Danish procedure can be seen at work as far away as California, where they have found a lucrative, multi-million dollar export market. Some 8,000 wind generators totalling over 650 megawatts have been erected in that state since 1981, and the Danish manufacturers account for between one quarter to one third of this. Several recent studies, some produced by the Electric Power Research Institute, have found the Danish machines to be the most reliable of the bunch. Of course, most of the wind turbines in California run reliably when properly operated.

In Canada the situation has been different. Unless a Canadian manufacturer can obtain support to have a prototype evaluated at our national test center through specific government programs, they must pay for their own testing.

When we look again at the 53 Canadian demonstration projects, we see that the manufactured--rather than home-built--machines consist of some 10 brand names. Only a few of these systems were manufactured in Canada, most were imported from the U.S., and none of them were first evaluated at a Canada's test facility. This means that at least some system failures otherwise need not have occoured. Certainly it would have added to the project costs to install each machine at the test center, but if a dozen of the 53 demonstration machines came from one manufacturer, then only one of the dozen would have done this.

Two things are worth noting, here. First, we can say all of this today with the benefit of hindsight. Those dozen examples of the same model were probably installed in four different provinces, mainly through separate provincial iniatives which were not centrally administered. Second, in order for the Canadian government to pursue, say, the Danish procedure and openly fund the evaluation of commercial prototypes at a national test facility, it would first have to decide that this technology warrants market incentives to compensate for the myriad of incentives going to the other, established energy industries, which are the actual competitors to our industry.

By funding demonstrations of wind technology without providing compensatory market incentives, one may wonder exactly what the federal and provincial governments intended. Certainly many of the staff hired by the provinces, at least, were inexperienced. I did find one report of a project judge who liked to fund machines that would not work, and the bureaucrat who told me this was not laughing.

3. MARKET INCENTIVES

By and large, federal involvement in wind power development has focussed on Canadian technology but has ignored foreign technology. By that I mean some foreign-built machines have been successfully commercialized, and can be seriously considered for commercial projects in Canada. but it is believed Canadian technology is not ready for commercial projects because the research isn't finished yet, and because cost reductions are still neccessary in order to compete with utility power plants, for example.

We can tell that there is some reliable hardware with a meaningful amount of commercial experience under it's belt. There are 8,000 turbines in California, 1,300 in Denmark, about 1,000 in the Netherlands, and even a few dozen going up in India. And that is so because their respective governments have given wind power the benefit of the doubt. In Canada, our governments have doubted the benefits by denial.

In many of the one-page demonstration project summary sheets, especially the ones dealing with grid-connected machines, it is concluded the respective systems are not presently economical compared with existing electricity options, like utility-supplied power. Much, if not all of this is due to the fact that utility power is subsidized in one form or another, especially the newer, more expensive power plants. which is why Canada has too many of them and consumes too much electricity. As it has been found in the U.S. and Europe, when comparable incentives are given to wind projects in the windier locations, their costs, relative to new utility power plants, are immediately attractive. It would work out that way whether wind power receives market incentives or conventional energy industries' incentives were removed.

4. NEW R&D POLICIES

As EMR gets down to a new wind energy program, I think one of the best bangs for the buck would come from extracting as much knowledge and experience out of the previous demonstration projects as possible. There's a lot to learn from these 53 machines, like the effects of severe cold, ice accumulation, perhaps the effects of improper system installation or inadequate system design.

One demonstration project even tried to develop a standard performance monitoring device, but did not succeed. Had it done so, perhaps the device would have been made available for use on the demonstration project turbines. If such a device became available now, it could be very cost-effective to install it on the turbines which have survived, and who's operation and maintenance is already borne by the system owners.

If the industry and EMR are to sit down and work out a wind power program, they should first step back and put it into perspective with the current status of the market. It remains EMR's responsibility to be involved with market participation just as it is now their responsibility to be involved with technology research.

As we look forward, we need to accurately determine the marketing issues and discuss their parameters. The private sector is already confronting the matter of market incentives with the Department of Finance and some of the electric utilities. Until we know what the cost viability threshold really is, behind the subsidies, it would be premature to set cost-reduction goals in our research and engineering activities.

Members of the existing, domestic wind power industry can not afford it any other way, whether they hope to market systems of their own design, to market imported machines, or bid on branch plant work for foreign manufacturers. I think this cost threshold information can be found if you look for it, but it has not yet been accepted by Ottawa or the provinces.

5. CONCLUSION

As the domestic market improves for wind systems, we may find the companies quickest to exploit it will be the ones with the greatest financial resources available, the broadest field experience and the most reliable, proven hardware. Attempts by Canadian distributors to market some of the Danish machines in Canada are already under way, and as the market incentives begin to drop in the U.S., wind suppliers there are growing hungry for new markets in other countries. We are about to face some serious competition in our own country from manufacturers and developers with hundreds of machines and millions of hours of experience.

The Americans don't seem to mind having branch plants for European manufacturers. Several are now being opened, built partially with regional job-creation and investment incentives. Why should it matter to Canadian suppliers who they buy turbines from? They will still push down the institutional barriers for marketing, and pursue their incentives, and they will be able to do this because the systems they sell will have longer commercial track records than ours will.

Both industry and government should be very careful when they consider what the next chapter of our wind program should be, and what its goals are going to be. There's plenty of room in this counry for the foreign competition, they've been given alot more support than we have and they're still getting it.

Thank you.

CANADIAN WIND ENERGY INDUSTRY — THE ROAD TO COMMERCIAL DEVELOPMENT

by Georgia Printzios

Wind energy has long been recognized as a potentially abundant supply of clean and renewable, mechanical and electrical power which has been used for centuries.

In the early seventies the severe effects of shortages and escalating prices of oil in North America began the process of a renewal of interest in alternative energy sources.

However, the intensified interest in the development of wind energy arrived in the 1980s with the introduction of federal tax credits for wind energy investment in the United States, particularly in the State of California.

The challenge that is facing the wind energy industry in North America is this: How do we manage to sustain the momentum generated through the investment community with these tax benefits coming to a close at the end of this year?

Two recent studies support the view that wind energy will soon, if not already, be competitive with conventional energy sources.

During the early sixties, the National Research Council of Canada embarked on a wind energy research program to serve Canada's energy needs and contribute to an ever-expanding international market.

Hence came the evolution of the low solidity Vertical Axis Wind Turbine technology as a reliable and cost effective wind energy conversion system.

NRC's active support both technically and financially to the newly emerging Canadian wind energy industry, has created the following challenge: How to develop wind energy systems which would ensure not only a good return on investment but a great return on investment.

In response to this challenge, the Canadian wind energy industry is well on its way towards commercial development of large scale wind energy conversion systems.

The Californian experience in wind energy development reinforces an undisputable claim. Wind energy has emerged as the one and only form of renewable energy capable of competing with conventional forms of energy, but at the same time demonstrating significant economic benefits to the industry.

It is noteworthy to mention that this claim is reinforced by the fact that in a short span of three and a half years California wind turbine installations have reached well over one thousand megawatts of generating capacity. That's the equivalent of a medium sized nuclear power station which takes more than 10 years to construct and billions, yes, billions of dollars.

This year the expenditure of the U.S. market is estimated in excess of one and a half billion dollars for wind energy development — not insignificant by any means. Clearly the economic benefits to the emerging wind energy industry are quite profound.

By being a labour intensive product and incorporating a wide spectrum of advanced technology and highly developed electrical and mechanical subsystems, it clearly offers the best of both worlds — the glitter of high technology and the proven soundness of conventional manufacturing techniques.

In terms of employment, a typical intermediate-size unit has the same employment requirements needed to assemble 20 automobiles.

Let us now examine briefly the market potential for wind energy.

The potential electric power production in Canada and the U.S. from available wind energy exceeds 1000 Gigawatts, a magnitude far greater than the present combined generating capacities of the two nations.

Within the twentieth century, conservatively speaking, the electric utility wind turbine market in the U.S. will be eight to ten billion dollars. This will be supplemented by a 200 million dollar rural market and 300 million dollars in stand-alone systems. The international market is at least of the same magnitude.

Seventy per cent of Southern California Edison's generating plants are oil or gas fueled. Southern California Edison has stated that each turbine the size of a MOD-2 that it installs, will displace about 15000 barrels of costly low sulphur imported oil per year. To meet its 1990 goal of 360 megawatts it would require 144 turbines the size of a MOD-2. This would result in an annual savings of over two million barrels of oil.

Similarly in Canada, an immediate market exists in the form of remote community applications. More important is the potential market for wind farm applications in the coastal regions where electricity is generated by oil-fueled power plants.

There are at least 10 sizeable regions each with requirements of more than three megawatts. The total installed capacity would be in excess of 100 megawatts suitable for large wind farm development.

INTERNATIONAL MARKET

(1) Europe

By the end of 1984 there was a total of 25 megawatts of generating capacity from 400 wind turbines having an average capacity of 60 kilowatts installed in European countries.

According to the European economic community projections, in excess of 1400 turbines will be installed by 1989 in Europe with an average capacity of 170 kilowatts. The total generating capacity will reach 250 megawatts.

(2) The Far East

In the Far East countries there was approximately one megawatt of installed capacity from about 40 turbines having an average capacity of 25 kilowatts, by the end of 1984. Increased activity is reported underway in India and Japan.

Although there are not as many good wind areas in the Far East as in other regions of the world, predictions are for 210 megawatts of capacity by the end of 1989.

(3) Australia

By the end of 1984 Australia had an estimated capacity of only one megawatt from 30 wind turbines having an average capacity of 30 kilowatts. Several demonstration projects including small wind farms in Perth and Tasmania should be underway in 1985.

In the long run the market in Australia is for small, stand-alone wind systems. Estimates are for 80 megawatts of wind generating capacity for 1000 turbines having an average capacity of 80 kilowatts to be installed in Australia by 1989.

(4) The Islands

Islands, in general, possess excellent wind sites. They also face both the high transportation cost of conventional fuel and the high cost of the fuel as well.

Two groups of islands are of interest – the Caribbean and the Pacific.

Many islands in the Caribbean are ideal for wind power applications. In these locations electricity costs, in general, are above 20 cents per kilowatt-hour. Based upon population and the need for electricity, a potential of 200 to 400 megawatts or a 300 to 600 million dollar market easily exists.

The Pacific is a large area where several island groups may be good markets. The most notable one is Hawaii where electricity currently costs 16 cents per kilowatt-hour. Wind energy is already in use there in the form of demonstration projects and the islands can easily absorb 400 to 500 megawatts within the twentieth century.

Guam and the Mariannas represent another excellent market. As the most westerly located American territory, Guam is quickly becoming a financial centre in the Far East. As far as wind energy potential is concerned, Guam is second only to Hawaii.

Islands around Taiwan also possess the necessary conditions for the use of wind. Diesel fuel is now shipped in to provide power which is vital to the defence of Taiwan.

Costs of electricity on these islands range from 14 cents per kilowatt-hour at the low end to 33 cents per kilowatt-hour at the high end. A market of 50 to 1000 megawatts exists.

The Phillipines is a nation of islands. The total number is somewhere near 7000. The Phillipines are in desperate need of energy. The government has allocated over nine billion dollars for the development of geothermal power on some of the larger islands in the next decade. Based on the population, 1000 to 2000 megawatts potential exists easily.

(5) South America

The best coastal area in South America lies in the southern part of Argentina where land is flat and the population sparse. It is believed that this area could be developed into a major energy supply when hydro power is developed concurrently. Lockheed Missile and Space Company has already been approached to do a system study of this potential. An early estimate indicates that at least 20,000 to 30,000 megawatts of wind potential exists. This is a good application for large utility wind turbines.

(6) The Third World

As an alternative energy source, wind is looked upon favourably by the Third World nations. Both UNESCO and the World Bank encourage the development of wind energy, and both agencies have expressed interest in providing financial support. Intermediate and small sized turbines are best suited for this market. Literally tens of thousands of megawatt potential exists as this market opens up.

The preceding information illustrates that wind energy technology is on the brink of commercial maturity and phenomenal growth, especially in the United States.

However, severe institutional and governmental barriers in Canada prevent the realization of rapid commercial development by this Canadian industry.

Elimination of these barriers is paramount especially when the Canadian wind energy industry is beginning to deliver its claim for renewable energy which is clean, safe and profitable. This, of course, is in addition to the significant contribution to Canada's employment market.

That Canada has technological leadership in wind energy development is indisputable. But whether or not this leadership quality eventually translates into tangible economic benefits for Canadians will depend on the further encouragement and support for this exciting new industry — an industry whose full potential has yet to be disclosed.

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WIND RESOURCE/WIND TURBINE HYBRID SYSTEM

OPERATION AND PERFORMANCE OF A WIND-DIESEL HYBRID POWER SYSTEM[1]

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Earth Energy Systems
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ABSTRACT

Hybrid power systems combine renewable power sources with diesel engine generators to provide continuous AC electrical power. Locations which depend on diesel fuel as their primary energy source can use hybrid systems to reduce energy costs. This paper describes a wind-diesel hybrid power system installed by Earth Energy Systems Inc. (EESI) at their engineering facility in Plymouth, Minnesota, USA. The system has been used for both product development and to gain long-term operating experience.

The sources of power generation, both manufactured by EESI, are a Winco three-phase 55 kW diesel generator set and two 12.5 kW Jacobs wind energy systems. The wind turbines have variable speed synchronous generators and single-phase line-commutated inverters. The wind systems and diesel generator set are tied in parallel to provide power to the engineering facility. The inverters have been modified to allow a programmable controller to alter the field voltage of the synchronous generator.

Development testing has provided information on the interaction of the wind systems, diesel generator and loads. Test data collected includes power production, fuel flow, and harmonic distortion. During operation, the wind has provided from 0 to 90 % of the power to the load. The hybrid system has been operated continuously since Oct. 4, 1985, except for maintenance on the diesel generator. A programmable controller has been used to logically control the wind energy systems and loads. The tests have proven that a wind-diesel hybrid power system is technically feasible and a viable alternative.

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INTRODUCTION

There are over 800 diesel generator sets with an aggregate rating of over 500 MW providing electricity to more than 300 Canadian communities that are not connected to major power grids (Chappell, 1985). Where the wind regime is appropriate, wind energy can be used to reduce diesel fuel consumption. The electricity from wind energy conversion systems can be used directly, with diesel generators providing the remainder. The delivered cost of diesel fuel depends on the distance and difficulty of transporting the fuel. To be cost effective the savings in diesel fuel must be greater then the cost of the wind system.

Several research and development projects have been conducted (Wilreaker et al., 1984; Chappell, 1985) which use either mechanical or electric power from the wind to replace diesel power. A wind energy conversion system producing mechanical power can be more efficient than one producing electrical power, but the load matching capabilities and flexibility in site selection of an electricity-producing system can be more practical. Studies indicate that substantial fuel savings are possible with a wind-assisted diesel generating system in wind regimes with an average annual windspeed above 5.5 m/s.

The Earth Energy Systems Inc. (EESI) hybrid power system combines diesel engine generators with wind turbines to supply electricity to remote areas. This paper provides information on an EESI wind-diesel hybrid system that provides AC electric power. There are three basic elements to the system: 1) diesel engine generators 2) wind turbines 3) programmable system controller. The wind turbines operate in parallel with the diesel generators to displace fuel usage. The programmable controller operates the diesel generators, regulates the wind turbines, and controls selected loads.

SYSTEM DESCRIPTION

The system being tested is comprised of one Winco diesel generator and two Jacobs wind energy conversion system (Fig. 1). The diesel generator is rated for stand by operation at 55 kW and provides three-phase 240 V electric power. The 12.5 kW wind turbines with 7.0 and 8.8 m diameter rotors have variable speed synchronous generators and single-phase line commutated inverters. One inverter is directly connected to the electric system while the second employs a isolation transformer. The wind systems and diesel generator set are tied in parallel to the engineering facility.

OPERATING EXPERIENCES

The EESI engineering facility in Plymouth, MN contains offices and laboratories. The load is primary lighting and resistive heating. However, several microcomputers and electronic test equipment are operated within the building. The peak load occurs during the day and is normally between 15 and 20 kW. The base load, which occurs at night, is from 2 to 3 kW. This facility provides a 'worst-case' scenerio for a hybrid system. The diesel generator and wind system capacity are relatively large for the load.

A programable controller has been interfaced with the hybrid system to provide logical control. Two resistive loads, of 6.5 kW each, are used as 'excess' loads for the system. If the wind turbine output reduces the load on the diesel generator below 5 kW then a excess load is added. If both resistive loads have been added and diesel power drops below 5 kW, wind power is reduced. The controller will first reduce the power output of each wind systems by lowering the field voltage of the alternator. If a further power reduction is required the controller will remove the field of the alternator, thus reducing the wind systems power output to zero.

The adding of excess loads and the reduction of wind power are for abnormal circumstances. There are used to insure that wind power will never be greater then the load on the system.

The hybrid system was first tested under static conditions to establish baseline data. Wind penetration was obtained from 0 to 90 %. Penetration is amount of wind produced power relative to the total load on the system. No abnormal variations in system operation were noted. Beginning on October 4, 1985 the system has been operated continuously without failure, except for maintenance on the diesel generator.

PERFORMANCE

The system was operated without wind power to establish the baseline data for fuel consumption versus diesel power output (Fig. 2). The relationship for fuel flow is linear with 3.6 L/h at no load and 14.0 L/h at full load.

A typical 'windy' day for the hybrid system occured on Nov. 20, 1985. Power for the load from the diesel and wind generators versus time are shown in Figure 3. Wind power from the two wind system was greater in the morning with a reduction in the afternoon. There is a one-to one relationship between wind power produced and load reduction on the diesel generator. For example, 10 kWh of wind-produced electricity replaced 10 kWh of diesel-produced energy between 2:00 and 3:00. The fuel consumption of the diesel generator during the same time period is shown in Fig. 4. The wind-produced electricity reduced the fuel consumption of the diesel. Fig. 5 shows the fuel flow versus diesel generator power output for the time period. Fuel consumption at a specific diesel generator output did not increase with the wind-diesel combination. The total energy produced for the day was 576 kWh with 200 kWh from the wind system and 367 kWh from the diesel generator set. Average penetration for the day was 35%.

The increase in distortion of the electricity for a hybrid system was monitored. Figure 6 shows the total harmonic distortion of the voltage from one wind system with an isolation transformer. Distortion does not increase until more than 50% of the power is supplied by the wind system. At a penetration of 80% the total harmonic distortion is less than 6%.

SUMMARY

A hybrid system consisting of a 55 kW diesel generator, two single-phase 12.5 kw wind energy conversion systems, and a programmable controller have been operated continuously since Oct. 4, 1985. The wind systems have provided up to 90% of the power requirements for the EESI engineering facility in Plymouth, Minnesota.

Development testing has provided information on the interaction of the wind systems, diesel generators and loads. During operational testing no abnormal operation has been observed. Fuel savings have been proportional to the amount of wind power available. The tests have proven that a wind-diesel hybrid power system is technically feasible and a viable alternative for reducing dependence on diesel fuel.

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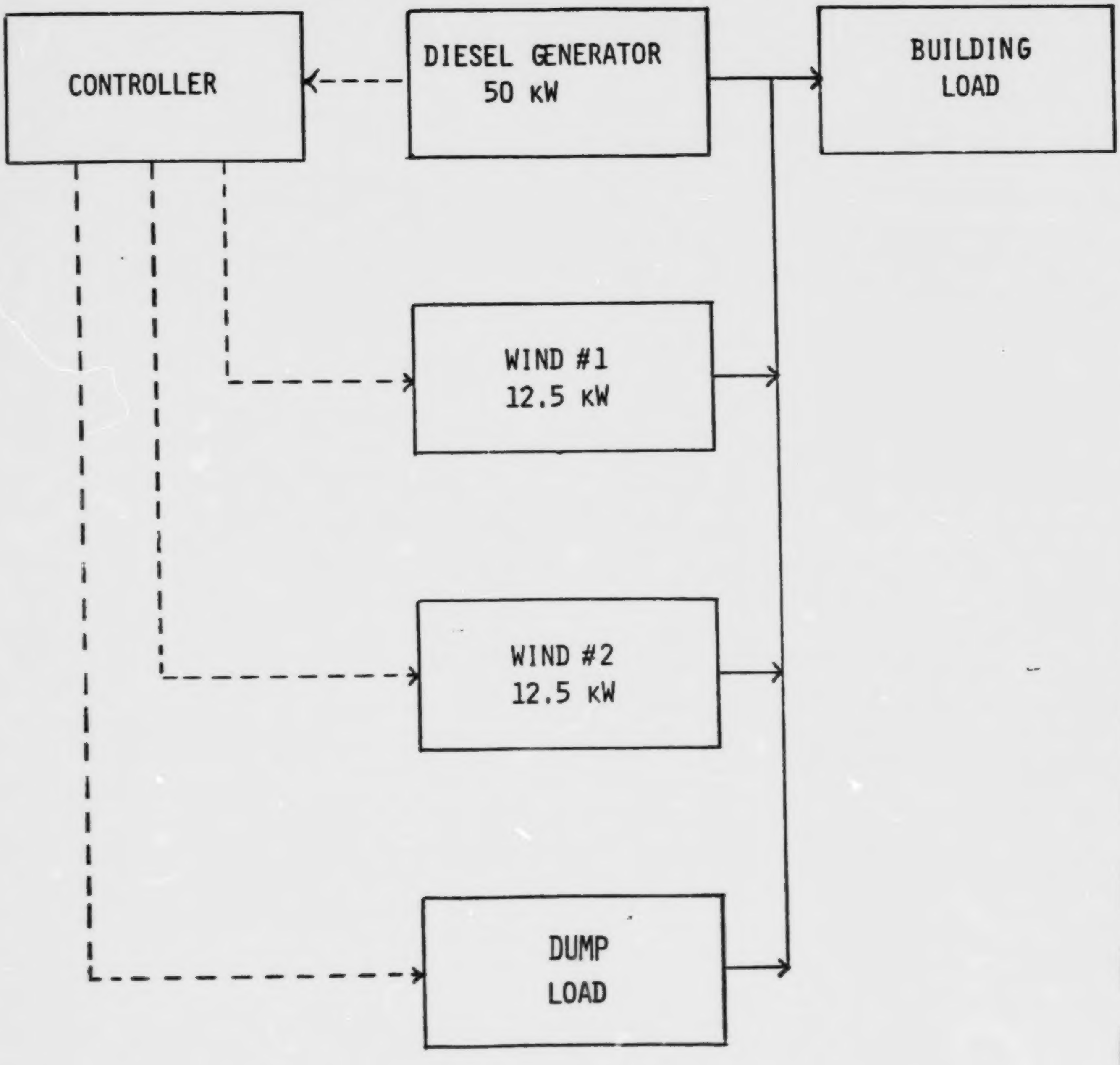
CONTROLLER
DIESEL GENERATOR
50 kW
BUILDING
LOAD
WIND #1
12.5 kW
WIND #2
12.5 kW
DUMP
LOAD

Fig. 1. Block diagram of hybrid system at EESI Engineering facility in Plymouth, Minnesota USA.

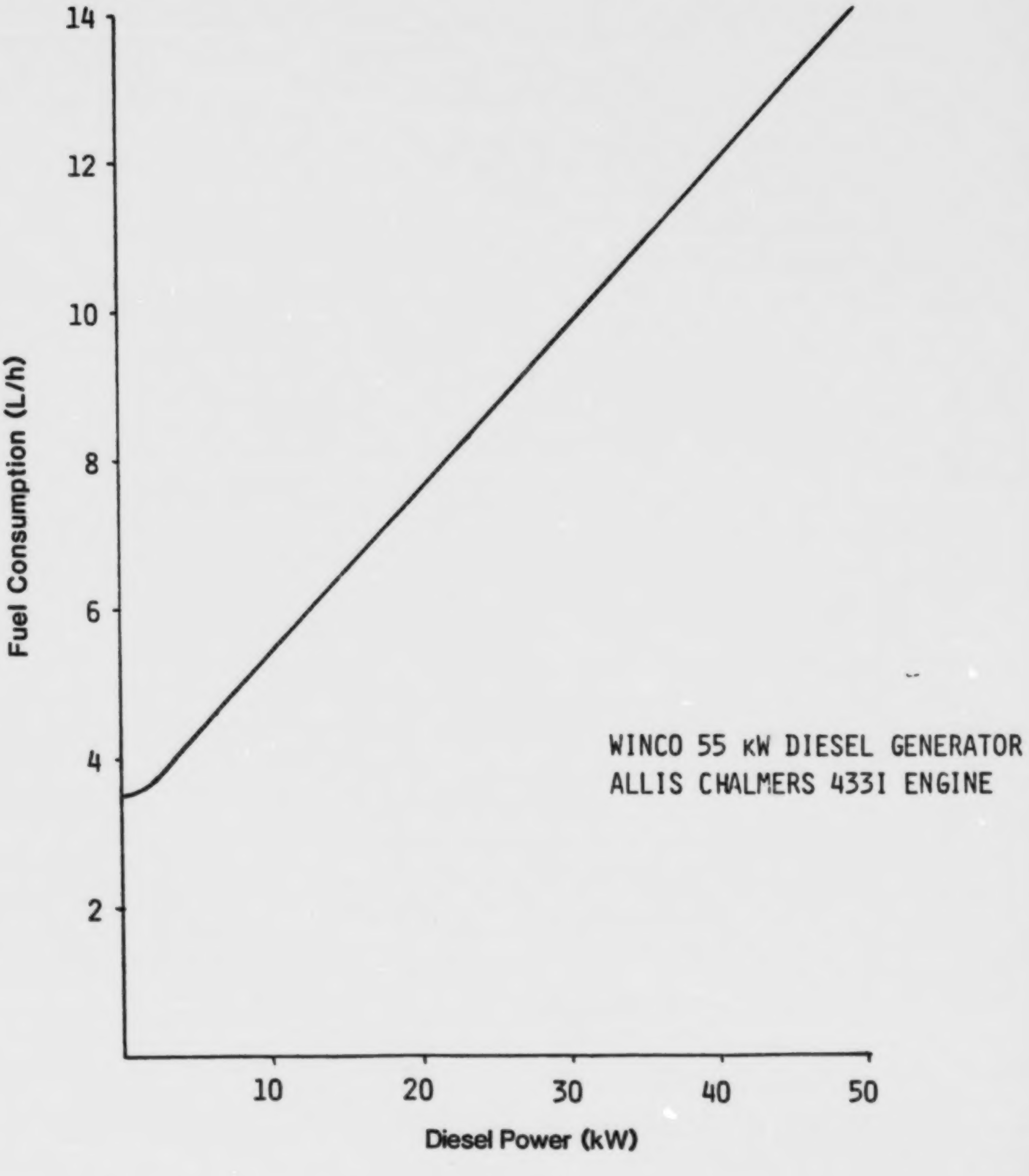

FIG. 2. FUEL CONSUMPTION OF DIESEL GENERATOR SET AT 0° C.

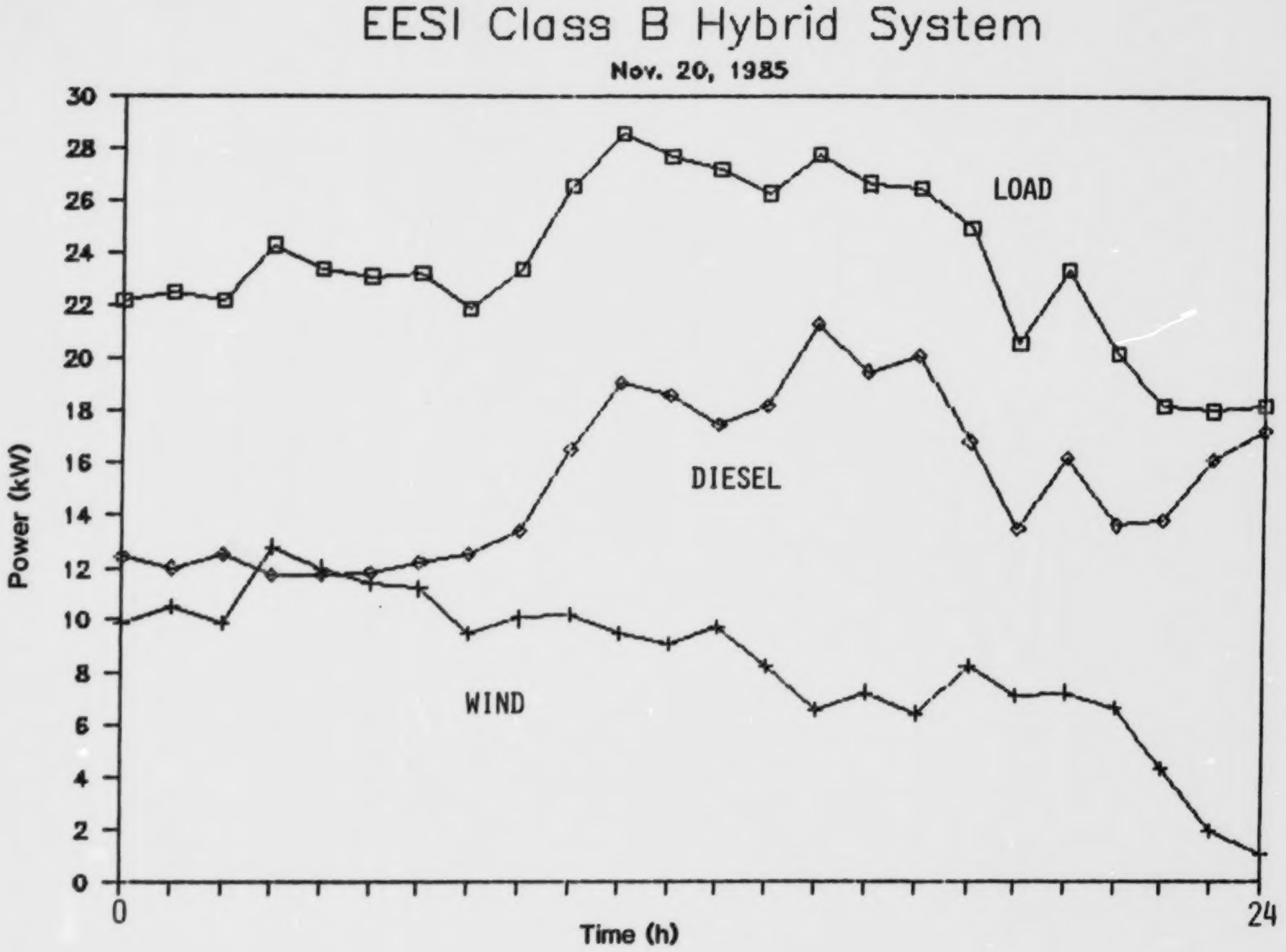

FIG. 3. POWER PRODUCTION AND CONSUMPTION OF HYBRID SYSTEM ON NOV. 20, 1985.

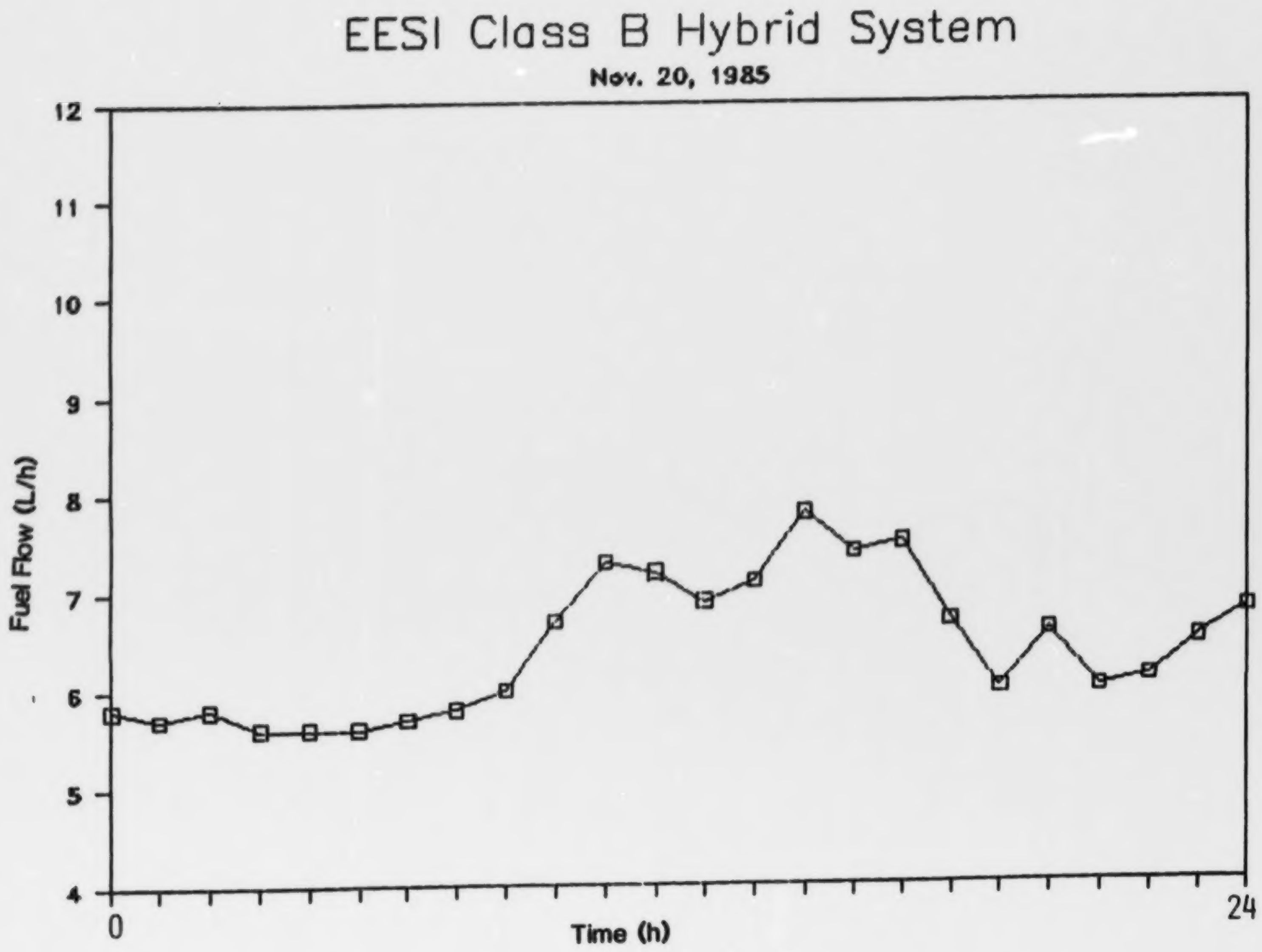

Fig. 4. Fuel consumption of hybrid system on Nov. 20, 1985.

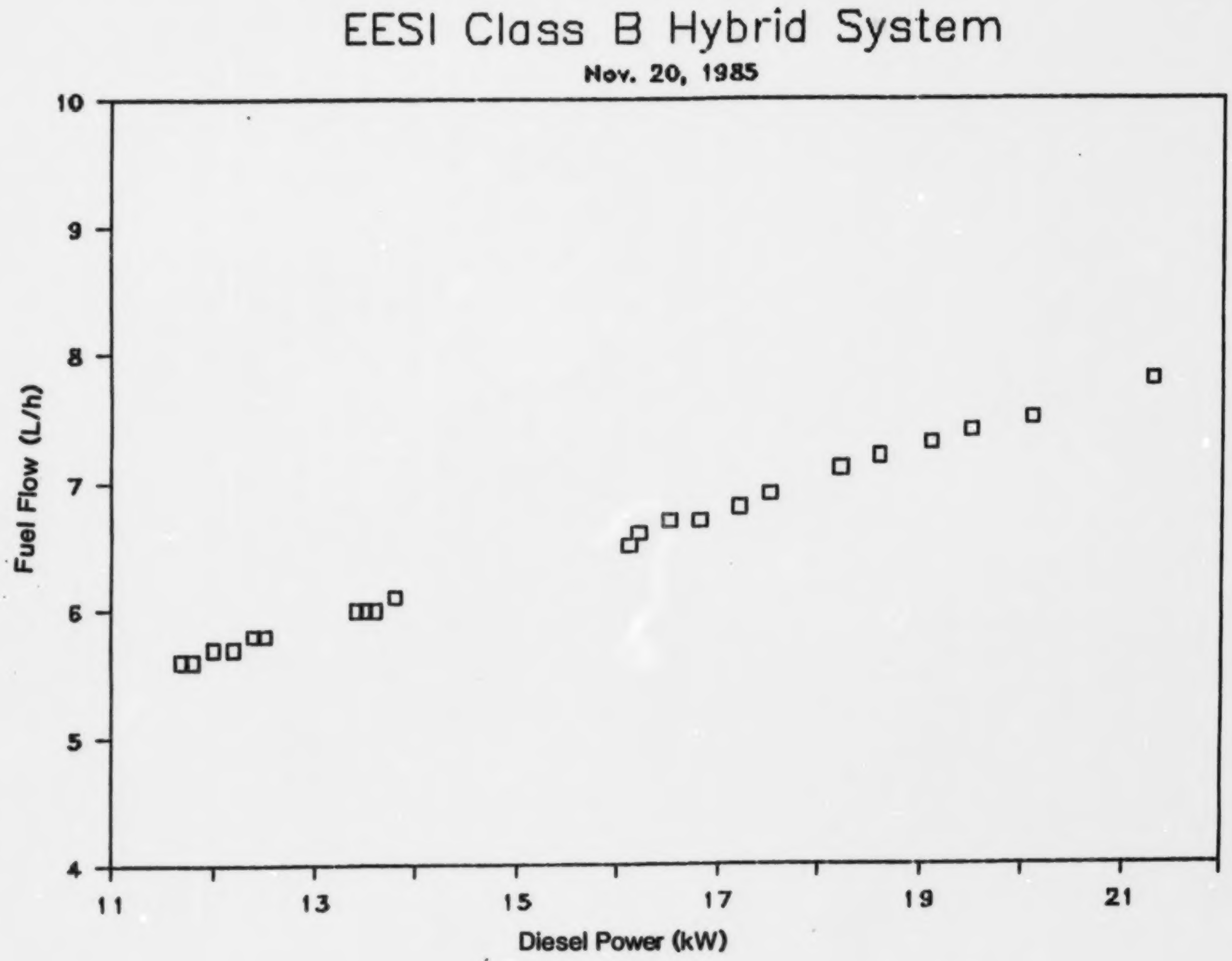

FIG. 5. FUEL CONSUMPTION OF DIESEL GENERATOR ON NOV. 20, 1985.

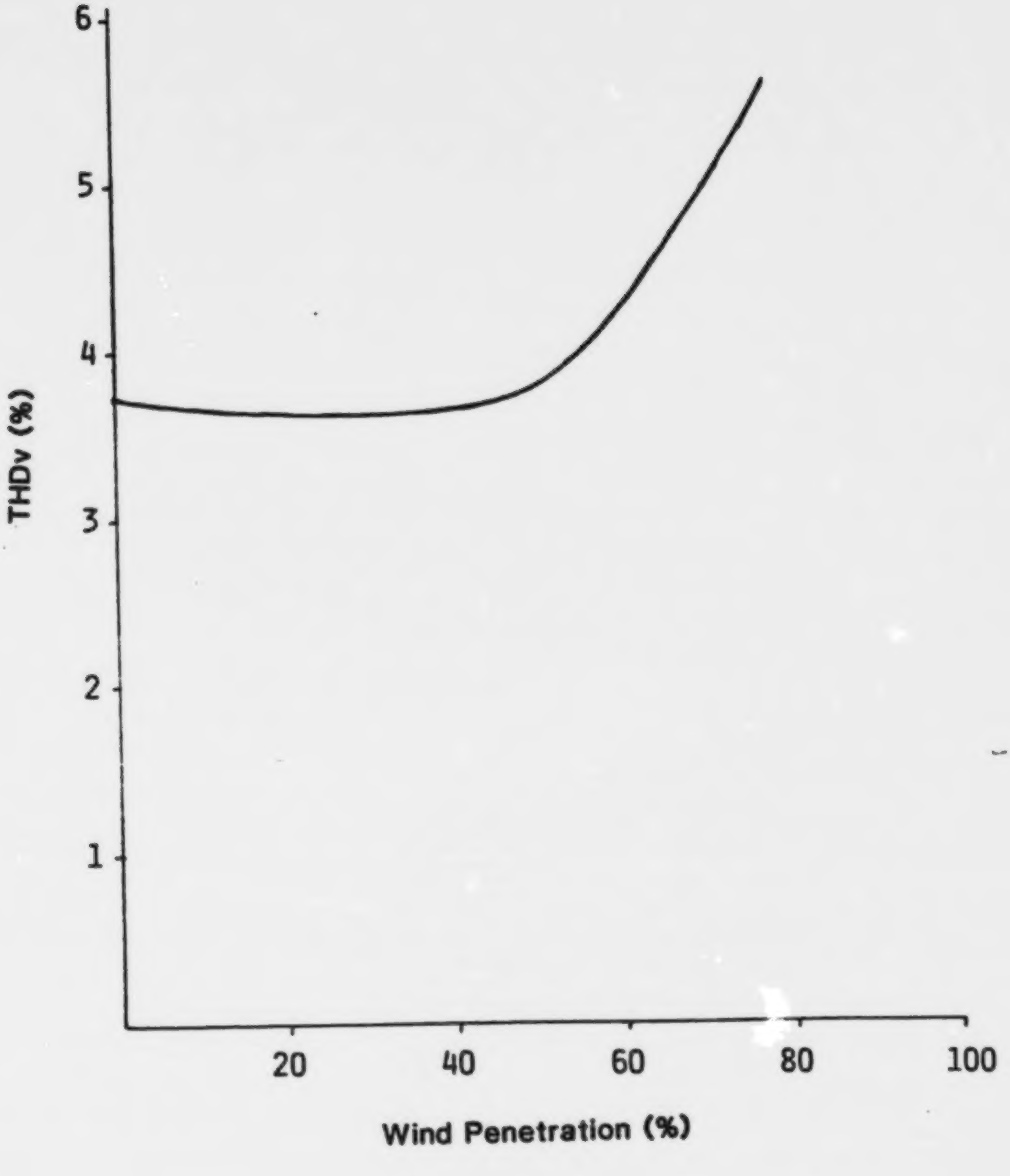

Fig. 6. Total harmonic distortion of voltage with 0 to 12 kW of wind-generated power from an isolated single-phase inverter.

EVALUATION OF METHODS OF FITTING THE WEIBULL DISTRIBUTION TO OBSERVED WIND SPEED DISTRIBUTIONS FOR WIND ENERGY APPLICATIONS

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ABSTRACT

Seven methods of fitting the Weibull distribution to observed wind speed distributions and the Rayleigh distribution were evaluated for use in wind energy applications. The evaluation was based on estimating the annual wind energy production at 144 Canadian locations of two turbines in the 20-50 KW range from their power curves and the fitted analytical wind speed frequency distributions and comparing the results with the same calculation using the observed wind speed distributions. The weighted least squares method was found to estimate the Weibull distribution parameters that best represent the observed wind speed frequency distribution for this purpose. The Rayleigh distribution performed poorly in this regard except at the windiest locations.

1. INTRODUCTION

For many applications the Weibull distribution suitably represents observed wind speed distributions. In particular, for wind energy applications, the Weibull distribution (or the Rayleigh, a special case of the Weibull distribution), representing the wind speed distribution, is used in conjunction with the power curves of wind turbines to estimate the energy output of the turbine. However, since the observed wind speed distribution is rarely, if ever, described exactly by the Weibull distribution then different methods of fitting the Weibull distribution to the observed distribution will result in different estimates of the parameters of the distribution. As a consequence, the estimate of turbine energy production can vary with the method chosen to estimate the Weibull distribution parameters.

Although some authors ([1], [2]) have evaluated the merits of the various fitting methods, such as the chi-square goodness of fit test, none performed the comparison utilizing end-use procedures of the analytical distributions. The purpose of this work was to specifically evaluate different fitting methods of the Weibull distribution and the Rayleigh distribution for use with turbine power curves for estimation of annual energy production.

2. METHODOLOGY

The general approach taken was first to estimate the annual energy production of two wind turbines at each of 144 Canadian locations using the turbine power curves with the observed wind speed frequency distribution. This calculation constitutes the "observation" of energy production for each turbine at each site. The parameters of the Weibull distribution were then estimated using seven different methods, resulting in seven sets of Weibull parameters. The energy production of each turbine for each site was then estimated using the turbine power curve and the analytical Rayleigh and Weibull distribution with the seven sets of parameters representing the wind speed distribution. These values represent the "estimates". Appropriate error statistics were then calculated to determine which fitting method produced the best "estimate". Essentially this procedure evaluates how well each method fits the Weibull distribution to the part of the wind speed frequency distribution that contributes to the energy production of the turbine.

3. THE WEIBULL DISTRIBUTION

Many excellent discriptions of the Weibull and Rayleigh distributions and their use for wind energy applications are found in references [2], [3], [4] and [5].

The probability density function (PDF), f(v), of the Weibull distribution is given by:

$$f(v) = (k/c)\ (v/c)^{k-1}\ \exp(-(v/c)^{k}) \qquad \ldots (1)$$

where the shape factor k (dimensionless) and the scale factor c (units of wind speed) are the Weibull parameters. Wind speed (v) units are kilometres per hour. The value of c can be converted to, expressed in and used in any appropriate wind speed unit. The cumulative density function (CDF), F(v), expresses the probability that the wind speed is greater than or equal to v and is given by:

$$F(v) = \int_{0}^{v} f(V)\ dV = 1 - \exp(-(v/c)^{k}) \qquad \ldots (2)$$

The nth non-central moment of the distribution is expressed by:

$$\overline{v^{n}} = c^{n}\ \Gamma(1+n/k) \qquad \ldots (3)$$

where Γ is the gamma function (tabulated in standard mathematical tables) and the over bar denotes a mean quantity. In particular, the first moment of the distribution (mean wind speed), $\bar{v}$, is:

$$\bar{v} = c\ \Gamma(1+1/k) \qquad \ldots (4)$$

The Rayleigh distribution, a special case of the Weibull distribution obtained by setting k=2, is expressed by:

$$f(v) = 2\ v/c^2\ \exp(-(v/c)^2) \qquad \ldots (5)$$

Graphical representation of the Weibull PDF appears in Fig. 1. For k>1, f(0)=0 and f(v) exhibits a single maximum. The peakedness of the PDF increases for increasing k. Alternately the dispersion increases for decreasing k. For k=3.5 the distribution is approximately Gaussian. For k=1, f(0)=1/c and the distribution is monotonically decreasing for v>0. For k>1, f(v) assymptotically approaches the v=0 axis and decreases monotonically for v>0.

4. WIND SPEED OBSERVATIONS

The observed wind speed distributions were compiled from data sets prepared at the Alberta Research Council for the purpose of a national wind energy analysis. This work is reported in [5]. The wind speed observations were taken from the National Climatological Archive at the Atmospheric Environment Service, Downsiew, Ontario. Frequency distributions were compiled for each of 144 Canadian locations from ten-year hourly data sets for the period 1967-76. The wind speed measurements are one-minute averaged wind speeds observed on the hour. Most anemometer heights above ground are 10m. At the twenty locations where anemometer heights were other than 10m the individual wind speeds observations were adjusted to 10m using the Irwin formualtion of the power law model [6] before the frequency distribution was calculated.

The wind speed class size of the frequency distributions of observed wind speed used in all calculations was 1 km/h, the unit of wind speed used in the National Climatological Archive. The numerical form of the discrete frequency distribution was z_i, i=0,1,2,3,...,139 where z_i is the relative frequeny of occurrance of wind speed i km/h. The discrete cumulative observed distribution took the form Z_i, i=0,1,2,3,.....,139, where Z_i is the relative frequency of wind speeds less than or equal to i km/h.

The locations for which this analysis was performed and summary statistics are listed in the Appendix.

5. METHODS OF FITTING

5.1 General Methodology

The methods used to fit the Weibull distribution to the observed frequency distribution were gleaned from the meteorological and wind engineering literature. Seven methods of fitting the Weibull distribution and the Rayleigh distribution were chosen and are described in the following sections.

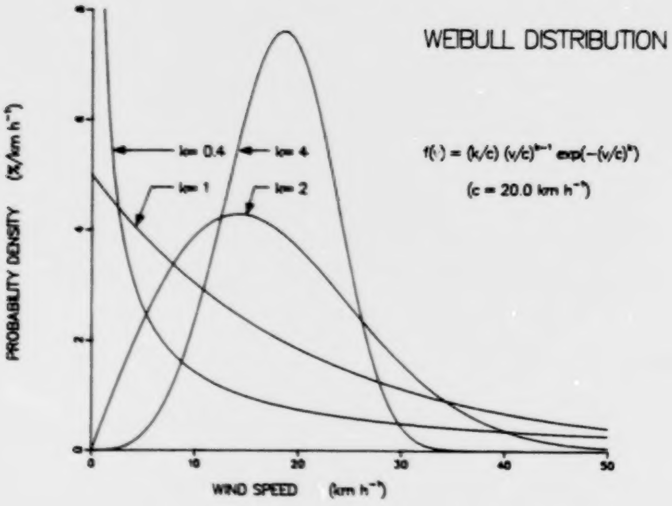

Figure 1. Shape of the Weibull distribution for various values of the shape factor k

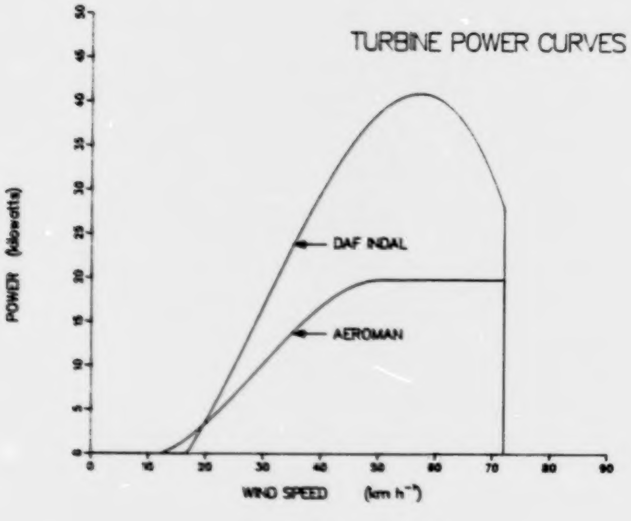

Figure 2. Power Curves for the DAF INDAL and AEROMAN Wind Turbines

Since many statistics or properties of the Weibull distribution, such as the dispersion or moments, can be expressed in terms of the distribution paramenters, the parameters are estimated by calculating the statistics or properties of the observed distribution and then assuming that the wind speeds are Weibull distributed with the same values of the calculated properties.

5.2 Least Squares, Unweighted

The method of least squares is one of the most common and easily executed fitting methods. It is a simple to perform on a calculator, computer or by graphical methods as described in [8] and [9].

The CDF described in equation (4) is transformed to the discrete linear form $y_i = a+bx_i$ by the relationships:

$$x_i = \ln(v_i) \qquad \ldots (7)$$

$$y_i = \ln[-\ln(1-Z_i)] \qquad \ldots (8)$$

where the subscript i refers to the wind speed i km/h. The linear coefficients a and b are then determined by least squares linear regression. The Weibull parameters k and c are calculated by:

$$c = \exp(-a/b) \qquad \ldots (9)$$

$$k = b \qquad \ldots (10)$$

The least squares algorithm was performed for all wind speeds between 3 kmh and the highest v_i for which cumulative probability Z_i did not exceed 0.99. All wind speeds were unweighted.

5.3 Least Squares, Weighted

This method is identical to that in 5.2, except that the range of points v_i, Z_i used in the least squares algorithm was limited to the wind speeds between the approximate cut-in and cut-out speeds of the turbines ($15 < i < 73$). The weighting factors used were 1.0 for points within this range and 0.0 for points outside this range.

5.4 Moments

The method of moments is described in [4]. The two important moments of the wind speed distribution are generally considered to be the mean of the wind speed and the mean of the cube of the wind speed (since wind power varies as the wind speed cubed). From equation (3) the two moments $\bar{v}$ and $\bar{v}^3$ are given by:

$$\bar{v} = c\Gamma(1+1/k) \qquad \ldots(11)$$

and

$$\bar{v}^3 = c^3\Gamma(1+3/k) \qquad \ldots(12)$$

$\bar{v}$ and $\bar{v}^3$ are calculated directly from the observed distribution then, and from (11) and (12), k is evaluated by iteration from:

$$k=[3\bar{v}^3\Gamma(3/k)]/[\bar{v}^3\Gamma^3(1+1/k)] \qquad \ldots(13)$$

c is then obtained from (11).

5.5 Maximum Likelihood

The method of maximum likelihood is described in [5] and [8]. The Weibull distribution parameters are estimated by the iterative solution of:

$$c = \left(\left(\sum_{i=0}^{139} A_i v_i \right) / N \right)^{1/k} \qquad \ldots(14)$$

$$1/k = \left(\sum_{i=0}^{139} A_i v_i^k \ln v_i \right) / \left(\sum_{i=0}^{139} A_i v_i^k \right) - \sum_{i=0}^{139} A_i \ln v_i / N \qquad \ldots(15)$$

where N is the total number of observations, v_i is the mid point of the ith wind speed class (in this case $v_i = i$), n is the total number of wind speed classes (140), and A_i is the number of observations in the ith wind speed class.

5.6 Fractile 10,90

The p fractile wind speed is defined ([5]) as the value of wind speed v_p such that

$$F(v_p) = p = 1 - \exp(-(v_p/c)^{-k}) \qquad \ldots(16)$$

v_p is thus the wind speed which exceeds fraction p of all observations. Given two observational points $(v_{p_1}, p1)$ and $(v_{p_2}, p2)$ k and c are estimated from:

$$k = a / (\ln(v_{p_1}) - \ln(v_{p_2})) \qquad \ldots(17)$$

and

$$c = \exp(w \ln(v_{p_1}) + (1-w) \ln(v_{p_2})) \qquad \ldots(18)$$

where

$$0 < p1 < p2 < 1 \qquad \text{...(19)}$$

$$w = 1 - \ln(a_1) / a \qquad \text{...(20)}$$

$$a = \ln(-\ln(1-p1)) - \ln(-\ln(1-p2)) \qquad \text{...(21)}$$

$$\text{and } a_1 = -\ln(1-p1) \qquad \text{...(22)}$$

The 10,90 fractile method uses $p1=0.1$ and $p2=0.9$ and the corresponding observational values of $v_{.1}$ and $v_{.9}$.

5.7 Fractile 25,75

The 25,75 fractile method is the fractile method described in 5.6 above with $p1=0.25$ and $p2=0.75$ fractiles and corresponding obsevational wind speeds $v_{.25}$ and $v_{.75}$.

5.8 Mean, Standard Deviation

k and c can are estimated from the mean, $\bar{v}$, and standard deviation, σ, of the wind speed by (see [10]):

$$k = (\sigma / \bar{v})^{-1.086} \qquad \text{...(23)}$$

which is an approximate form of

$$(\sigma/\bar{v})^2 = (\Gamma(1+2/k) / \Gamma^2(1+1/k))^{-1} \qquad \text{...(24)}$$

and from

$$c = \bar{v}/\Gamma(1+1/k) \qquad \text{...(25)}$$

This method is convenient if the mean and standard deviation of the wind speed distribution are already known.

5.9 Rayleigh

For the Rayleigh distribution k is set equal to 2. This leaves only the scale factor c to be estimated from equation (4) by:

$$c = \bar{v}/\Gamma(3/2) = 0.88623\ \bar{v} \qquad \text{...(26)}$$

6. WIND TURBINE POWER CURVES

Annual mean energy production was estimated for two wind turbines, the 50 KW DAF INDAL vertical axis turbine and the AEROMAN horizontal axis turbine. The turbine power curves are shown in Fig. 2 and are based on the following equations where P is the turbine power output in watts for wind speed v (km/h).

AEROMAN: $P(v) = 0$ for $v < 14.4$,

$= 1950 - 653\ v + 47\ v^2 - 0.54\ v^3$

for $14.4 < v < 50.4$,

$= 19300$ for $50.4 < v < 72$,

$= 0$ for $v > 72$ ...(27)

DAF INDAL: $P(v) = 0$ for $v > 16.8$,

$= -8447 - 228\ v + 53\ v^2 - 0.6\ v^3$

for $16.8 < v < 72$,

$= 0$ for $v > 72$ ...(28)

The hub or equator height of each is approximately 10 m. These formulations of the power curves were obtained from [11] and were chosen because they are representative of 20 to 50 KW turbines with which 10m wind statistics are used.

7. WIND ENERGY CALCULATIONS

7.1 Observed Annual Energy Output

The average power, Pj, for each turbine at site j, j=1,2,3,...,144, based on the power curves and observed frequency distributions is given by:

$$P_j = \sum_{i=0}^{139} P\ (v_i)\ x_i \qquad \text{...(29)}$$

where x_i is the observed relative frequency of occurrence of speed v_i. The average energy output (joules), Oj, from each site was calculated by:

$$O_j = P_j\ T \qquad \text{...(30)}$$

where T is the number of seconds in a year. O_j thus represents the "observed" annual energy total for each site.

7.2 Estimated Annual Energy Output

The average power, P_j, for each turbine for each site j for each set of Weibull distribution parameters, k and c, resulting from each fitting method was calculated by:

$$P_j = \int_0^\infty P_j(v)\ f(v)\ dv \qquad \text{...(31)}$$

Simpson's Rule was used to perform the integration.

The "estimated" average annual energy, E_j (joules), for each turbine for each fitting method was calculated by:

$$E_j = P_j\, T \qquad \ldots(32)$$

8. EVALUATION STATISTICS

Two evaluation statistics, the mean bias error (MBE) and root mean square error (RMSE), were claculated for each turbine and each fitting method. For a given fitting method and turbine, the errors, expressed as percentages, are calculated by:

$$\mathrm{MBE} = \Sigma\,(E_j - O_j)\ /\ \Sigma O_j \times 100\% \qquad \ldots(33)$$

$$\mathrm{RMSE} = N/\Sigma O_j \qquad (\Sigma\,(E_j - O_j)^2\ /\ N)^{1/2} \times 100\% \qquad \ldots(34)$$

where the summation is taken over N ($j = 1, 2, \ldots, N$) locations. N is as large as 144 for all locations but was sometimes smaller when the errors were calculated for subsets of the full set of locations.

The MBE expresses the percentage error for each fitting method averaged over a set of locations. The MBE provides a measure of overall bias but does not give any indication of the size of individual errors since negative and positive errors at individual locations partially cancel.

The RMSE provides the square root of the average of the square of the individual errors as a percentage. Negative and positive errors do not cancel. Large individual errors are given a heavy weighting. This statistic is the most important measure of merit since it indicates the fitting method that performs best, most of the time.

9. RESULTS

9.1 Discussion

Results of each fitting method are shown in Table 1 for two locations, Cape Dyer, NWT (east coast of Baffin Island), and St. Lawrence, Newfoundland (south coast of the island of Newfoundland). St. Lawrence is an example of most exposed, at least moderately windy, "well behaved" locations. The percent occurrance of calms is low and the observed frequency distribution conforms moderately well to the Weibull distribution, as witnessed by the general agreement amongst all Weibull distribution fitting methods. Values of k at such sites generally range from 1.4 to 2.4. Cape Dyer is an example of a location where the Weibull distribution does not describe the observed distribution particularly well. There is a substantial range (from 0.4 to 1.0) in the values of k that result from each method. Such sites are characterized by low mean wind speeds, high frequency of occurrance of calm winds, and low values of the shape factor k. The Rayleigh distribution often does

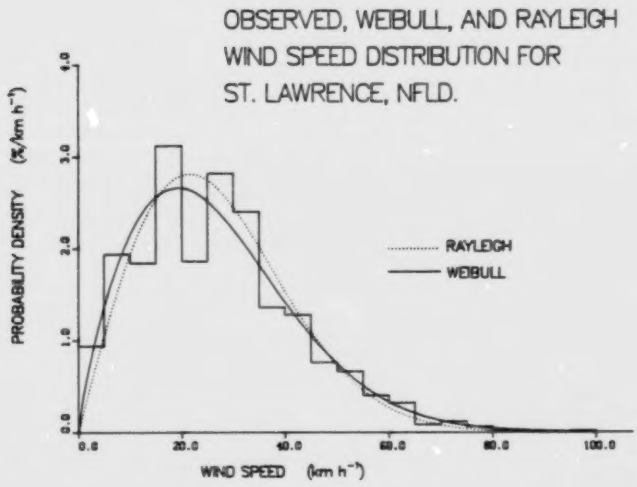

Figure 3. Observed Wind Speed Frequency Histogram, the Weibull Distribution fitted using the weighted least squares, and the Rayleigh distribution for St. Lawrence, Newfoundland

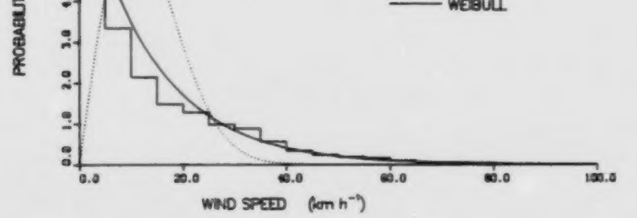

Figure 4. Observed Wind Speed Frequency Histogram, the Weibull Distribution fitted using the weighted least squares, and the Rayleigh distribution for Cape Dyer, N.W.T.

not describe such wind regimes well and can result in large errors. The observed wind speed distribution at 5 km/h class intervals, the Rayleigh distribution and the Weibull distribution using the parameters resulting from the weighted least squares method are presented for St. Lawrence and Cape Dyer in Figs. 2 and 3. The poor fit of Rayleigh distribution at Cape Dyer is evident from Fig. 3 and from the fact that the error at Cape Dyer for estimating the annual energy production of the DAF INDAL turbine using the Rayleigh distribution was -66.0%. The corresponding error for the weighted least squares method was -4.1%.

The error statistics are presented in Tables 2,3,and 4. Table 2 shows the statistics for all 144 Canadian locations. Tables 3 and 4 show the summary statistics for locations having a mean wind speed greater that 15 km/h (75 locations) and greater than 20 km/h (20 locations), respectively. The methods are ranked by the RMSE score.

Several aspects of the statistics are prominent. The weighted least squares method is ranked first with respect to minimum RMSE for each turbine and for each set of location groupings. MBE's are generally small, the largest absolute value being 2.3%, and for the grouping of locations having mean wind speeds greater than 20 km/h, the MBE's are close to zero. The weighted least squares fitting procedure performs best based on these results. The list of anemometer locations, the Weibull scale and shape factors, c and k, determined by this method, and the annual energy output of each turbine estimated from the observed wind speed distribution are listed in the Appendix.

The performance of the Rayleigh distribution was generally poor compared to that of the Weibull distribution with any of the methods of fitting the parameters. The Rayleigh distribution was consistently ranked last or close to last in Tables 2 and 3 with RMSE's ranging as high as 21.6%. The performance greatly improved for the grouping of locations having mean speeds greater than 20 km/h. The RMSE's for both turbines are less than 5% and the MBE's -0.4 and 0.2%. The dramatic improvement of the performance of the Rayleigh distribution at windy locations is due to the fact that the wind speeds tend to be Rayleigh distributed at these sites to a greater degree than at less windy sites. Inspection of the shape factors from the Appendix for the 20 locations having mean speeds greater than 20 km/h reveals that the median value of k is 1.9, 8 of the k values are between 1.9 and 2.1, 14 of the k's are between 1.8 and 2.2 and all are between 1.5 and 2.2. For sites exhibiting mean speeds less than 20 km/h the percentage of calm winds increases and the speeds become less Rayleigh distributed.

Other general comments on the seven Weibull distribution fitting methods are that (1) for locations having wind speeds greater than 20 km/h (Table 4) all methods except the 10,90 fractile method scored RMSE's 5% or less; (2) for locations having wind speeds greater than 15 km/h (Table 3) all methods except the 10,90 and 25,75 fractile methods scored RMSE's 5% or less; (3) considering all locations (table 2) the weighted and unweighted least squares method, method of moments, and mean, standard deviation method all scored RMSE's 5% or less.

Caution should be exercised in the use of these results. The Weibull distribution parameters presented in the Appendix were estimated from a population of one-minute mean wind speeds whereas the turbine power curves were derived from wind speeds averaged over at least ten minutes. Since the population of one-minute mean speeds will show slightly higher dispersion (lower shape factor) than a population of ten-minute or longer average speeds, the estimate of energy output will be slightly high using either the observed wind speed distribution or the derived Weibull distribution. In practice this is probably somewhat compensated by the slight negative bias exhibited by the weighted least square method.

Climatological wind speed should always be applied with consideration of the anemometer exposure. The sites used for this analysis are almost all located at airports. Exposure is generally good with respect to the sheltering effects of buildings, terrain or vegetation. On the other hand, airports are often not located in the windiest areas such as exposed coasts or mountain passes. Individual site descriptions of the sites used in this analysis are available from [11].

The Weibull distribution parameters estimated by the weighted least squares method are presented in the Appendix and are recommended for use for wind energy applications especially for use with power curves for turbines in the 20-50 KW range. They are not intended for purposes that depend on the wind speed distribution for wind speeds less than 15 km/h or greater than 73 km/h since large departures from the observed distribution could result, especially for locations having low mean wind speeds.

9.2

TABLE 1

COMPARISON OF WEIBULL DISTRIBUTION PARAMETERS RESULTING FROM VARIOUS FITTING METHODS

	Location			
	Cape Dyer, NWT		St Lawrence, NFLD	
Mean Wind Speed (KM/H)		13.1		27.0
Frequency of Calms (%)		26.3		3.3
Method	**C (KM/H)**	**K**	**C (KM/H)**	**K**
LS,U	12.2	.9	30.1	1.7
LS,W	14.0	1.0	30.2	1.8
MOMENTS	12.6	.9	30.4	1.8
F25,75	8.9	.4	30.7	1.9
F10,90	8.4	.6	31.1	1.9
M,SD	12.2	.9	30.4	1.8
ML	10.6	.7	29.8	1.7
RAYLEIGH	11.6	2.0	30.5	2.0

Note: LS,U and LS,W denote least squares, unweighted and weighted;
F10,90 and F27,75 denote 10,90 and 25,75 fractile methods;
M,SD denotes mean, standard deviation; ML denotes maximum likelihood

9.3 TABLE 2

ERROR STATISTICS FOR METHODS OF FITTING THE WEIBULL DISTRIBUTION FOR 144 LOCATIONS

DAF INDAL			AEROMAN		
Method	RMSE(%)	MBE(%)	Method	RMSE(%)	MBE(%)
LS,W	3.7	-2.3	LS,W	2.0	-.9
M,SD	3.9	-1.4	M,SD	3.4	-1.4
MOMENTS	4.7	-2.5	MOMENTS	4.2	-2.3
LS,U	5.0	-.1	LS,U	4.5	-1.0
ML	11.0	6.6	ML	7.7	3.1
F10,90	13.9	-3.8	F25,75	13.6	7.5
F25,75	17.8	9.3	F10,90	14.1	-6.4
RAYLEIGH	21.6	-16.9	RAYLEIGH	16.7	-12.8

9.4 TABLE 3

ERROR STATISTICS FOR METHODS OF FITTING THE WEIBULL DIST'N FOR LOCATIONS (75) HAVING MEAN WIND SPEED > 15 KM/H

DAF INDAL			AEROMAN		
Method	RMSE(%)	MBE(%)	Method	RMSE(%)	MBE(%)
LS,W	2.8	-1.5	LS,W	1.7	-.7
M,SD	2.9	-1.2	M,SD	2.4	-1.0
MOMENTS	3.1	-1.5	MOMENTS	2.7	-1.2
LS,U	4.0	-.8	LS,U	3.8	-1.3
ML	4.9	1.2	ML	4.0	-.6
F25,75	8.7	3.3	F25,75	7.1	3.2
F10,90	10.9	-6.1	RAYLEIGH	7.8	-5.2
RAYLEIGH	11.4	-7.9	F10,90	11.3	-6.3

9.5 TABLE 4

ERROR STATISTICS FOR METHODS OF FITTING THE WEIBULL DIST'N FOR LOCATIONS (20) HAVING MEAN WIND SPEED > 20 KM/H

DAF INDAL			AEROMAN		
Method	RMSE(%)	MBE(%)	Method	RMSE(%)	MBE(%)
LS,W	2.0	.0	LS,W	1.5	.1
MOMENTS	2.3	-.4	MOMENTS	1.9	-.5
M,SD	2.5	-.2	M,SD	2.0	-.3
F25,75	3.8	-1.6	F25,75	2.9	-1.1
ML	4.0	-2.0	RAYLEIGH	3.3	.2
LS,U	4.1	-.8	LS,U	3.8	-1.3
RAYLEIGH	4.6	-.4	ML	4.3	-2.6
F10,90	8.4	-1.9	F10,90	7.9	3.5

10. CONCLUSIONS

For the purpose of fitting the Weibull distribution to observed wind speed distributions to estimate the energy output of turbines in the 20-50 KW rated power range, the least squares method, weighted to wind speeds between typical cut-in and cut-out speeds (15 and 73 km/h), performed well over all ranges of mean wind speed and was judged to be best.

Other fitting methods, specifically the unweighted least squares method, method of moments, and the mean, standard deviation method also performed well.

The Rayleigh distribution, when evaluated for the same purpose, performed poorly except at locations having mean wind speeds greater than 20 km/h.

11. ACKNOWLEDGEMENTS

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14. APPENDIX

Listing by province of the locations used in the analysis along with:

1) The Mean Wind Speed (km/h)
2) Weibull distribution scale (c) and shape (k) factors estimated by the weighted least squares method
3) Annual estimated energy production of DAF INDAL and AEROMAN turbines estimated from the observed wind frequency distribution

Location	C (km/h)	K	Mean Speed (km/h)	Annual Energy (GJ)	
				DAF INDAL	AEROMAN
THE YUKON					
Burwash A	14.4	1.3	11.7	106	71
Dawson	7.3	1.1	6.9	20	16
Watson Lake A	9.2	1.2	7.6	34	25
Whitehorse A	16.2	1.9	13.1	93	67
THE NORTHWEST TERRITORIES					
Baker Lake	24.8	1.7	21.6	300	184
Cambridge Bay A	26.4	1.8	23.2	335	204
Cape Dyer A	14.0	1.0	13.1	154	93
Cape Parry A	22.4	1.8	19.3	241	152
Coral Harbour A	21.6	1.5	19.5	233	146
Fort Simpson A	10.8	1.6	8.7	23	20
Fort Smith A	14.0	1.8	12.1	55	44
Frobisher Bay A	17.1	1.5	14.3	139	92
Hall Beach A	25.8	1.9	22.8	310	192
Hay River A	14.5	1.8	12.6	66	50
Inuvik A	11.6	1.6	10.1	33	28
Norman Wells A	14.3	1.4	12.3	90	62
Resolute A	24.4	1.6	21.5	305	184
Yellowknife	17.4	2.0	15.2	106	77
BRITISH COLUMBIA					
Abbotsford	11.4	1.2	11.2	66	46
Cape St James	37.3	1.8	33.2	531	302
Castlegar A	11.7	1.6	8.6	35	29
Comox A	13.4	1.1	12.3	114	73
Cranbrook A	13.4	1.5	11.1	70	50
Fort Nelson A	7.3	1.1	6.8	17	14
Fort St John A	17.4	1.8	15.2	125	86
Kamloops A	15.3	1.5	12.5	103	70
Kimberley A	11.6	1.3	9.9	57	41
Penticton A	15.1	1.6	12.3	91	64
Port Hardy A	12.7	1.1	11.7	106	68

Location	C (km/h)	K	Mean Speed (km/h)	Annual Energy (GJ) DAF INDAL	AEROMAN
Prince George A	12.3	1.4	10.3	60	43
Prince Rupert A	17.2	1.5	15.5	140	93
Quesnel A	9.1	1.2	6.5	27	22
Sandspit A	20.2	1.5	18.1	208	132
Smithers A	9.0	1.3	6.6	21	18
Spring Island	17.0	1.0	16.8	200	120
Terrace A	16.4	1.6	13.3	118	80
Tofino A	12.0	1.4	10.4	55	41
Vancouver Intl A	12.8	1.4	11.9	63	46
Victoria Intl A	11.3	1.4	10.9	47	35
Williams Lake A	12.6	1.4	10.3	63	45
ALBERTA					
Calgary Intl A	16.9	1.5	14.3	127	86
Cold Lake A	13.5	1.7	11.7	53	41
Coronation A	16.8	1.8	15.0	98	72
Edmonton Intl A	14.9	1.6	13.3	88	63
Edmonton Namao A	15.7	1.7	14.1	92	67
Fort Chipewyan A	12.6	1.7	9.8	38	32
Fort McMurray A	10.4	1.5	9.2	23	20
Grande Prairie A	14.7	1.3	13.0	114	74
Lethbridge A	19.6	1.4	18.0	210	130
Medicine Hat A	17.9	1.7	15.5	144	96
Peace River A	15.0	1.9	13.0	71	53
Red Deer A	15.7	1.7	14.3	92	68
Rocky Mountain House	9.1	1.3	8.7	25	21
Vermilion A	14.9	1.8	13.2	76	57
Whitecourt	10.3	1.5	8.2	26	22
SASKATCHEWAN					
Broadview	17.6	1.7	15.8	132	91
Estevan A	22.8	2.1	20.4	234	152
Moose Jaw A	21.1	1.8	18.5	209	135
North Battleford A	17.5	1.7	14.9	131	89
Prince Albert A	17.8	1.8	15.1	132	90
Regina A	22.4	1.9	19.9	232	149
Saskatoon A	20.0	1.9	17.8	174	116
Swift Current A	25.6	2.2	22.6	296	188
Uranium City A	14.1	1.8	11.6	59	45
Wynyard	19.9	1.9	17.9	172	116
Yorkton A	18.8	2.0	16.2	137	96
MANITOBA					
Brandon A	17.9	1.7	15.8	141	96
Churchill A	24.2	2.0	21.6	265	169

Location	C (km/h)	K	Mean Speed (km/h)	Annual Energy (GJ) DAF INDAL	AEROMAN
Dauphin A	20.0	1.7	17.7	192	124
Portage la Prairie A	18.6	1.9	16.4	137	95
The Pas A	18.0	2.0	15.5	124	87
Thompson A	15.1	1.9	12.7	67	52
Winnipeg Intl A	19.8	1.9	17.6	167	113
ONTARIO					
Atikokan	9.3	1.4	7.8	16	15
Big Trout Lake	16.9	1.8	15.0	106	76
Chapleau	15.2	1.9	11.9	70	53
Earlton A	16.7	2.2	13.7	82	64
Geraldton	14.5	1.7	12.2	68	51
Gore Bay A	19.5	1.9	17.0	161	109
Kapuskasing A	15.5	2.1	12.7	60	50
Kenora A	16.9	2.2	14.8	89	68
London A	17.2	1.9	15.0	108	79
Mount Forest	16.2	1.8	13.8	96	69
Muskoka A	14.5	2.1	12.9	46	41
North Bay A	14.9	1.9	13.2	64	50
Ottawa Intl A	16.2	1.7	14.7	101	72
Sault Ste Marie A	16.4	1.6	14.3	111	78
Simcoe	17.1	1.9	15.1	108	77
Sioux Lookout A	12.8	1.8	10.6	36	31
Sudbury A	21.9	2.0	19.5	209	138
Thunder Bay A	15.2	1.6	13.5	93	65
Timmins A	14.4	1.7	12.1	63	49
Toronto Intl A	16.7	1.6	15.1	119	82
Trenton A	17.7	1.8	15.4	126	88
White River	13.3	1.7	9.7	46	38
Wiarton A	18.6	1.9	16.0	143	98
Windsor A	18.8	1.8	16.7	148	101
QUEBEC					
Bagotville A	17.8	1.7	15.3	138	93
Baie Comeau A	18.2	1.7	16.3	146	98
Fort Chimo A	17.7	1.6	15.7	141	95
Grindstone Island	34.9	1.9	31.1	505	293
Lac Eon	15.6	1.8	12.6	84	62
Mont Joli A	22.8	2.0	20.2	240	154
Montreal Intl A	17.0	1.6	15.2	127	86
Nitchequon	17.3	1.6	15.3	134	90
Poste de la Baleine A	20.6	1.9	17.8	184	123
Quebec A	16.3	1.7	14.2	105	74
Riviere du Loup	16.2	2.0	13.8	82	62
Roberval A	16.4	1.8	13.9	99	71

Location	C (km/h)	K	Mean Speed (km/h)	Annual Energy (GJ) DAF INDAL	AEROMAN
Schefferville A	20.4	2.0	17.6	180	120
Sept-Iles A	18.1	1.7	16.2	139	95
Sherbrooke A	12.7	1.7	10.4	42	34
Ste Agathe des Monts	13.1	1.7	10.5	48	38
St Hubert A	18.5	1.7	16.1	148	100
Val d'Or A	14.8	1.9	12.7	65	50
NEW BRUNSWICK					
Charlo A	17.5	1.8	15.2	125	86
Chatham A	15.4	1.7	13.4	87	63
Fredericton A	16.3	1.8	14.0	100	71
Moncton A	18.2	1.9	16.2	132	92
Saint John A	19.8	1.9	17.2	168	114
PRINCE EDWARD ISLAND					
Charlottetown A	21.5	2.1	18.9	193	129
Summerside A	22.1	1.9	19.6	222	144
NOVA SCOTIA					
Greenwood A	18.1	1.6	15.5	155	102
Halifax Intl A	20.7	2.0	18.6	179	121
Sable Island	28.9	2.0	25.7	388	235
Shearwater A	17.7	1.7	15.7	129	89
Sydney A	22.7	1.9	20.1	233	151
Truro	15.9	1.8	13.3	89	65
Yarmouth A	21.3	1.9	18.8	203	134
NEWFOUNDLAND					
Battle Harbour LOR	29.2	2.1	25.7	389	236
Bonavista	31.9	2.2	28.1	457	272
Burgeo	26.9	1.7	23.9	356	213
Cartwright	22.7	1.7	20.1	252	157
Comfort Cove	20.9	2.1	18.5	173	119
Daniels Harbour	27.7	1.7	25.2	374	222
Deer Lake A	18.9	2.4	15.3	125	90
Gander Intl A	22.0	1.9	19.4	220	143
Goose A	18.0	1.7	15.9	140	95
Hopedale	22.7	1.8	19.8	245	155
Port aux Basques	25.6	1.7	22.6	314	192
St Lawrence	30.2	1.8	27.0	430	252
St John's A	27.4	2.1	24.1	340	210
Stephenville A	20.9	1.8	18.1	200	130
Wabush Lake A	17.7	2.0	14.6	112	81

Ft. Severn
WIND DIESEL HYBRID

The Ft. Severn Wind Diesel Hybrid Demonstration Project is being funded by Energy Mines and Resources through RCDP, by the Ontario Ministry of Energy and by the Canadian Electrical Association. The project will demonstrate the use of a wind turbine coupled to a small diesel power plant.

Location and Transportation:

Ft. Severn is the most northerly community in Ontario located on Hudsons Bay 50 km. east of the Manitoba border. There are no surface land routes that are regularily used into the village. At irregular intervals over the years a winter sled has made the 400 km. round trip journey from Churchill Manitoba, more frequently a barge has been towed the 600 km. from Moosonee. The town is 1600 km. NW of Toronto and travel there by plane requires a twelve hour journey. The scheduled aircraft fly in several times a week however any journey to Ft. Severn on a sheduled service requires an overnight stay, with the only accomadation being provided by the Ministry of Transport and Communication at the rate of $40/ night in very modest facilities.

Geography:

The land here is very flat and the trees are generally small the area is all muskeg the land was recently (in geological time frame) covered by Hudsons Bay that has been retreating as the land is slowly rebounding from the compressional effect of the Glaciers that covered this area. Hudsons Bay is now some 10 km. away and the town of Ft. Severn is built on an 'Esker' which is a sand bar 200ft wide running North/ South that is actually an old shoreline of the Bay. The river Severn is wide and fast at this point and runs 20 to 25 ft. below the town, it is of course frozen in the winter.

The People:

The village has recently recieved the status of an Indian reservation and has an Indian popuilation of approximately 300. The villagers are a contented band occupying themselves with hunting, fishing, wood gathering and building and maintaining their houses. The village has a school, a Hudsons Bay store and a band office and has had no central power or water system. A central water system had been installed some years ago however the system froze soon after installation and no attempt was made to revive it, this is now a priority again and an installation will probably be realised with the installation of the new power system being installed. The central power system is being installed by Ontario Hydro this year, it is anticipated that the lights will be on by Christmas.

The decision to install a wind turbine into this community was made some ten years ago:

Wind Turbines were identified as one of the more promising of the 'renewable energy' sources during the 1970's after the off-oil trend had been initiated by OPEC. During initial testing and development it became clear that the application of wind turbines in Canada would be restricted to those areas that are removed from the main utilitys. Low electricity costs associated hydropower, coal fired thermal and nuclear generation can not at this time be matched by wind turbines. Fortunately for wind turbine manufacturers like ourselves there are large and small communities that are 'remote' from the main electrical grid, these communities are predominately supplied by power from diesel generator sets with some small hydro. In Northern Canada especially, electricity is frequently generated by diesel generators where the diesel is delivered by plane; electricity costs in this area are typically 60c/ kWh and up, coincidentally this area has the best wind resource in the country. The Fort Severn Project is the culmination of a ten year effort to develop a wind/ diesel generating system suitable for these remote communities, the bulk of this work has been funded by the National Research Council of Canada, and has included Ontario Hydro as a technical advisor and participant.

The Toronto Island Project:

The Toronto Is. Project was commenced in 1976 was the first experiment in a series, this prototype 12 kW system was used to examine both mechanically and electrically coupled configurations together with their associated control systems. It was concluded that substantial fuel savings could be obtained from both mechanically and electrically coupled modes, with the greater savings being obtained with mechanical coupling. One significant problem that was identified during these tests was the power that was required to start the wind turbine could overload the diesel thus 'bringing the system down'. A scale up of the Toronto Island project was initiated in 1980, this was the -

Sudbury I Project:

This demonstration had a budget of $1 million and the basic hardware consisted of two 50 kW diesel generator sets, a 30 kW darrieus turbine mechanically coupled to one of the diesels, a dump load and a simulated community load. The experiment was declared to be a success, despite some problems that were apparent in the mechanical coupling, the practical disadvantages of having to position the wind turbine and the diesel in the same location were used to justify the continuing of the tests using electrical coupling, this became the .

Sudbury II Project:

Using the same basic hardware Sudbury 1 fuel saving was shown to be similar to the mechanically coupled configuration. Many problems were identified and solved in the control system and the operation of the dumploads. The fourth and final stage of the experiments was to move the wind turbine installation to Ft. Severn for proof of concept under real life conditions,

Contract and Schedule:

Ontario Hydro awarded Howden the contract for the Wind Turbine installation at Ft. Severn by in June of this year. Because of the short time frame we had made a decision during the initial tendering to plan to install the foundation in the Summer of 1985, the year before the planned wind turbine installation date of June 1986. We did this because of the small weather window at Ft. Severn, we were unable to supply the wind turbine to the site in time for erection during the Fall of 1985, we were not prepared to undertake the erection and commissioning during the Winter and did not wish to have the erection date pushed back any further by having to wait for the foundation installation during Summer 1986.

Foundation Design:

The soil report that had been undertaken by Dominion Soil Engineers had indicated that it was possible that some permafrost could be present at the site. Probing had encoutered discontinuous permafrost at a number of locations. In order to minimise the possibility of permafrost causing significant foundation mobility our civil engineers, Morrison Hershfield, elected to place the foundations shallow and covering a large area with insulation on the underside. This would ensure that whatever the permafrost conditions were below the pad they would remain unaffected by foundation installation. This approach involved designing the foundation as a floating raft structure. The foundation we have installed is a 0.6 m. thick reinforced, 7.5 m. square concrete slab sitting on 10 inches of SM insulation. The insulation will that there is no significant thermal conduction of heat to areas below the pad.

Foundation Installation:

The foundation materials were shipped by barge from Moosonee. This Summer was the first time for some four years that the barge has operated into Ft. Severn. Watching the progress of the barge it was easy to see why this service does not run regularily, the barge left in late September having been held up in Moosonee harbour nearly two months past the planned sailing date of July 26th. The reason for the delay was the ice in Hudsons Bay. When the ice did clear the barge only took three days to arrive at Ft. Severn river and another three days to free itself from the sandbank on which it ran aground. All in all it did not fill us with complete confidence on the reliability of this form of transportation. The barge carried the cement and rebar for the foundations, luckily the Esker on which Ft. Severn is built turned out to be an acceptable aggregate, our original plans had included the possibility of having to ship in our own aggregate sufficient for 70 cubic meters of concrete.

The foundation installation took three weeks and was completed in mid October using local labour, luckily the weather was mild for the time of year and did not present any further problems.

Wind Turbine.

The wind turbine that we will be supplying to Ft. Severn is a derivation of our HWP60 machine. The first HWP60 was erected in Scotland (U.K.) early this year and has now logged some 7000 hours, three other machines are now operating in Scotland and further machines will be erected soon. I beleive that the basic principles of operation of this machine are well known to everyone here so I am only going to describe the features that are unique to the machine that will be supplied to Ft. Severn, I call this the 'Remote Community Low Temperature HWP60'.

Power Plant Arrangement:

The power plant being installed at Ft. Severn consists of three diesels of different sizes, this allows the generating diesel to be selected on the basis of the system load size dependant which will be largely dependant on the time of day and climate. A programmable controller (pc) is included in the diesel building that will select the operating diesel to suit the load requirements, the pc will also control the operation of the wind turbine and will be able to limit the wind turbine output at times when the grid stability may be at risk.

Dump Load and Synchronous Generator:

The wind turbine includes a dump load rated at the full output of the wind turbine, this can be switched in in steps, the wind turbine includes its own programable controller that will respond to the requests from the system pc. The most common 'turn down' condition will be when the system is selecting a new diesel at this time the wind turbine output is throttled to a percentage of the maximum output, the percentage will vary depending on the scenario. Gusting conditions can also initiate power dumping.

For the Ft. Severn application we are supplying a synchronous generator, our engineers believe that it will be possible to achieve higher penetrations with the synchronous machine and for small applications like this the benefits of being able to control the power factor to close to unity without the problems associated with the possibility of self excitation are significant.

Low Temperature Requirements.

The impact of the low tempertures at Ft. Severn have a significant impact on the cost of this machine. Firstly a complete design review was required for all the structural components such as the tower and the foundation hold down bolts, other components that in the past were purchased as proprietry equipment became specials, a good example of this type of change is the low speed shaft of the gearbox.

Low Temp cont...

An order has been placed on our manufacturer for inclusion of special steel for the main shaft, requirements such as this have a snowball impact on costs by the time final assembly is undertaken. Heaters have been included in many components, the most critical being the programmable controller housing, low tempertaure trips are included at several locations.

Blade Design:

Another major change was that made to the blades. The design operating in th U.K. includes spring activated tip spoilers to protect the rotor from overspeed, design analysis indicated that reliability at low temperatures would be suspect, this together with concern that the spoilers would tend to accumulate ice under icing conditions resulted in the decision to remove the spoilers from this design. In their place we have included an extra disc brake in the drive train, the machine now has a brake on the low and high speed shafts.

Current Status:

The machine is presently being manufactured at our plant in Scotland. Shop assembly is scheduled to begin this month, the machine will be erected at the test site at the National Engineering Laboratories outside Glasgow in late January. There the machine will be coupled to a diesel generator and the integration strategy will be optimised during a two month test period. Shipping to Canada is scheduled for May 1986.

Installation:

Our original plans were to ship to Ft. Severn aboard a DC4, for airshipment the tower is in five sections as opposed to the standard two section design. Erection at Ft. Severn will be using a 'gin pole' and will be undertaken as early in the Summer as practicable. A two month commissioning and run in period will follow.

Future Plans.

For future machines in the North we see that a major cost saving can be realised by avoiding the double shipment that is associated with a concrete foundation. A plan has been developed to design a foundation that can be shipped to these remote sites at the same time as the wind turbine. Canadian sourcing is in hand and manufacturing and testing for future machines will be undertaken at our facilities in Montreal.

WIND/DIESEL/CYCLE CHARGE SYSTEM AT WINISK

Submitted to the First Annual Conference of the
Canadian Wind Energy Association (CanWEA)
at the Skyline Hotel, Ottawa, Ontario

December 9 - 10, 1985

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ATTACHMENTS

Appendix A
Appendix B

1 INTRODUCTION

The hundreds of small communities, government, and private establishments, spread throughout Canada's North have been identified to be the most attractive and appropriate locations for the use of small wind energy conversion systems (SWECS). Many are located in exposed coastal regions having good (5.5-6.5 m/s) annual average wind speeds. Because of their relatively small size and remoteness from normal shipping channels, they also have among the highest costs for petroleum fuels and electricity. Their small size and cold climate also mean that electricity is generated by diesel electric generators that burn high quality cold weather diesel fuel. Space heating requirements are also met primarily by burning light fuel oils. These loads peak during the long nights of the cold winter months. Fortunately, during these months wind speeds also reach their seasonal peaks.

No reliable or accurate estimates of the net cost savings to consumers or the effective reduction in fuel use based on actual demonstrated performance of SWECS are available. Surprisingly, there has been little effort by either the suppliers or the consumers of energy in the North to investigate and evaluate SWECS potential.

A project to design, install, and demonstrate a system based on wind/diesel cycle charge technology was conceived by the Ontario Ministry of Natural Resources (OMNR) in consultation with the Ontario Ministry of Energy (OME)--Renewable Energy Demonstration Office and Resource Ventures Incorporated (RVI). A project was proposed, developed, and presented to OMNR by RVI. The proposal was accepted by OMNR and a contract let to RVI to conduct a detailed investigation and prepare specifications and detailed estimates for the project. A report describing this work was prepared.[1] The report provided information on the existing facility, recommended renovations to enhance the thermal efficiency of the building, specifications for the wind/diesel cycle charge components, an estimate of capital and operating costs, and a preliminary economic evaluation.

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[1] Unpublished report to OMNR by RVI, "A Wind Powered Electricity Generating System for the Winisk Headquarters Building in Polar Bear Provincial Park", March 1984.

The design phase of the study for the wind powered electricity generating system for the headquarters building in Polar Bear Provincial Park at Winisk, Ontario included:

- choosing the configuration of the system;
- identifying the cost of equipment, materials, transportation, and labour required for installation, testing, commissioning, and monitoring of the system;
- carrying out a preliminary economic analysis of the system based on weather conditions, building design, and electrical loads expected at the site; and
- preparing design specifications for the electrical, mechanical, structural, and foundation components of the wind system suitable for tendering purposes.

A second phase of the program included a technical review of tenders; preparation, evaluation, and recommendations of plans for site work at Winisk; and monitoring and analysis of the system including calculation of energy output, availability, maintenance requirements, and a comparison of the results with predictions.

Prior to on-site construction it was deemed desirable to install and test the system at a more accessible site. The selection of an appropriate site, a description of the tests to be conducted, and a cost estimate and time schedule for the tests was prepared for the approval of OMNR as an intermediate step between the design and construction phases.

This paper on the history of the project details the essential steps taken to implement the system. The disadvantage of performing demonstrations of prototype equipment in such remote areas is obvious.

2 BACKGROUND

The main headquarters building on the site is a 9- room single-storey building containing a kitchen, five bedrooms, and two large spaces suitable for office or other common use. The 20 m X 8 m building was constructed in the early 1950s by the military. It is supported on concrete piles. Ceilings are 3 m high. The exterior is steel clad.

Insulation levels are uncertain but for estimating purposes it was assumed that walls are R-11 (RSI-1.94), ceilings are R-14 (RSI-2.46), and floor R-5 (RSI-0.88). Windows are conventional, metal sash and storm, double glazed units, typical of the era. Heat loss from the building was estimated at 430 watts per degree Celsius.

Heating has been provided by an oil-fired space heater with no distribution to separate areas of the building. Cooking and water heating are provided by propane. Electricity is supplied by a 10 kW air-cooled diesel generator located in a small shed about 50 metres from the main building. Water is transported from the Winisk River and stored in an external tank. A pump is used to pressurize the building water system.

The poor insulation and heating capability have limited building use to the warmer summer months. Winter quarters are rented from the Ontario Ministry of Communications who operate an air field and accommodation unit a few kilometres from the site.

3 DESIGN

Discussions were held with OMNR officials to develop a rationale for a design optimization and configuration of the building and its energy systems. The actions agreed upon and the resulting energy requirements of the renovated building and the shed for the diesel unit and storage batteries are reviewed below. In addition, the energy available from the wind and its application to the system loads are presented.

3.1 Building Renovations

To make the building suitable for winter use without excessive energy use, the building envelope must be improved. Recommended standards and actions for the renovations follow:

1. Insulate and vapour seal the walls to a minimum of R-31 (RSI-5.5).
2. Insulate and vapour seal ceilings to a minimum of R-54 (RSI-9.5).
3. Insulate and vapour seal the floor to a minimum of R-25 (RSI-4.4).

4. Install a third glazing on the interior of existing windows.
5. Seal and caulk all windows and frames to minimize infiltration.
6. Replace existing doors with insulated units (R-7.5, RSI-1.3).
7. Install an air-to-air heat exchanger to provide controlled ventilation.

Vapour barriers should be installed following the procedures established for the R-2000 residential housing demonstration program.

3.2 Building Energy Loads

3.2.1 Electrical Loads

In Table 1, the electrical appliances and fixtures expected to be used in the headquarters building and associated diesel shed are described and quantified. In the unoccupied condition, it is expected that 3.4 kW.h per day will be required to operate the freezer, inverter, and system controls. These loads will be in the diesel shed and will contribute heat to the shed.

When the building is occupied, it is expected that lighting will consume 2.7 kW.h per day; other uses such as food storage and preparation will consume 5.8 kW.h per day. While the building is occupied, the diesel shed is expected to consume slightly more electricity at 3.9 kW.h per day.

Because these loads will be supplied from batteries, it is necessary to generate approximately one-third more electricity to supply battery charge/discharge losses.

3.2.2 Heating Loads

A number of heating loads have been identified which are dependent on the seasonal temperatures and whether the building is occupied or not. All heating loads have been related to the 8674 heating degree days established for the area.

3.2.3 Water Store

During the coldest months, water deliveries from the Winisk River to the 4000 litre storage in the diesel shed will be heated to 6°C and maintained at that level. Dependent upon levels of occupancy, this will require between 25-40 kW.h per month. From May to September, no heat is required.

TABLE 1

Estimated Electrical Loads Supplied from Storage Batteries

Load	Type	Occupied kW.h/day	Unoccupied kW.h/day	Demand	
				Watts	Amps
Headquarters Building					
Lights					
Kitchen	dc	0.5	---	170	1.0
Bedrooms	dc	0.4	---	200	1.7
Bathroom	dc	0.2	---	40	0.3
Lounge	dc	1.2	---	200	1.7
Office	dc	0.4	---	120	1.0
Total Lights		2.7	---	680	5.7
Refrigerator	ac*	3.3	---	300	2.5
Air changer	ac*	0.3	---	60	0.5
Cooking (toaster, kettle)	dc	1.0	---	2500	20.0
Radio, etc.**	dc	1.2	---	100	0.8
Total		8.5	---	3640	29.5
Diesel Shed					
Pump	dc	0.4	---	350	3.0
Shed lights	dc	0.1	---	100	0.8
Inverter	dc	0.5	0.5	20	0.2
Freezer	ac*	1.7	1.7	300	2.5
Controls	dc	1.2	1.2	50	0.4
Total		3.9	3.4	820	6.9
GRAND TOTAL		12.4	3.4	4460	36.4

*Through inverter system
**Convenience inverters

3.2.4 Diesel Shed

The diesel shed was assumed to be constructed with R-25 (RSI-4.4) walls and floors, R-40 (RSI-7) ceiling, and an air change rate of one-half the volume of the building per hour. On this basis, heat loss was estimated at 23 W/°C. Heat gains from electrical equipment operating in the diesel shed was estimated at 153 W per hour. The shed will be kept at 5°C. It is expected that auxiliary heating will only be required for six months of the year.

3.2.5 Headquarters Building Heating

The building heat loss was estimated at 132 W/°C when insulated as described in Section 3.1. It was assumed that the building will be operated at 20°C when occupied. The electrical usage, cooking, and occupants were estimated to contribute 500 W per hour towards building heating requirements (free heat).

In the unoccupied condition, the building will be kept at 5°C. There will be no free heat because there is no demand for electricity in the unoccupied building. No allowance was made for reductions in heat load resulting from the use of an air-to-air heat exchanger.

3.2.6 Domestic Hot Water

It was assumed that 150 L per day of hot water will be required when the building is occupied. This will require 8 kW.h per day. It was assumed that cost for energy derived from propane will be the same as for oil.

3.2.7 Occupancy

A major factor in the energy to be used lies in the number of days the building is going to be occupied. In the analysis in Table 2, the energy usage is based on 5 days per month occupancy during December, January, February, and March; 10 days per month during April, October, and November; and 24 days per month during the remainder of the year.

3.2.8 Estimated Energy Requirements

The total generated electrical energy required per year is estimated to be just under 3,700 kW.h with heat energy at 22,000 kW.h for a total energy requirement of 25,700 kW.h.

3.3 Electrical

The electrical system in the building was of conventional military/industrial standards. Supply has been most recently provided by a 10 kW air-cooled diesel generator set located in a small shed about 50 metres from the facility.

The proposed electrical system shown schematically in Figure 1 is a hybrid installation that is to provide for both direct (dc) and alternating current (ac) distribution to the building's electrical loads.

The dc distribution system will be supplied directly from the battery bus. Alternating current loads such as the refrigerator, freezer, and vent fans will be supplied by one or more inverters powered from the battery bus. Special or emergency ac loads used occasionally may be supplied directly from the diesel generator.

Electric heaters supplied by the WECS are recommended as a means of providing the bulk of the building's heating load. A transfer switch may be desirable to enable manual control over the supply of building heating load by the diesel generator. The electric heaters should be thermostatically controlled by wall-mounted thermostats. Priority for heating spaces will be determined by relative settings of the thermostats and by the versatility of the WECS control unit.

Special requirements for the distribution system are the provision of physically distinguishable dc and ac outlets to protect both the system components and the user, and the provision of small portable convenience inverters to enable visitors to use small portable devices such as radios, minicomputers, and other 110 V ac-powered apparatus.

A pamphlet should be made available to new visitors to learn the unique features of the system. A little education regarding the features and limitations of the supply system will greatly enhance both the efficiency of energy use within the building and life expectancy of the battery storage system.

3.4 Wind System

The supply of electrical loads and a portion of the space heating requirement to the Winisk headquarters building by a wind energy system could be accomplished in a number of ways. The methods considered prior to selection of the recommended strategy shown in Figure 1 were:

1. WECS/Diesel Fuel Saving Mode:

In this configuration, a small WECS would be electrically paralleled with the output of a diesel generator. The WECS could use any of the following methods of generation to effect parallel operation with the diesel:

- o induction generator;
- o separately excited synchronous alternator;
- o permanent magnet alternator with rectifier and/or synchronous inverter; or
- o brushless dc generator with synchronous inverter.

This alternative would generally necessitate operation of the diesel when the building was in use even when loads were very low. The difficulty in providing stability to the system under low load and high wind conditions is an obvious constraint for such a system. The cost of fuel for the diesel would also be prohibitive for the relatively low load and demand.

2. Direct Heating:

An interesting alternative for heating a building in Canada's North is to use a WECS designed to convert all its mechanical output to heat. Generally such systems should be less costly than systems designed to supply electricity regulated and controlled for conventional use. This alternative could not be recommended however, since reliable, proven systems are not available. At least two small Canadian manufacturers[2] are building systems.

3. Stand Alone WECS with Battery Storage and Diesel or Gasoline Generator Backup:

This is the most often chosen alternative and one used for many years in rural America and Australia to supply reliable power to off-grid farms and ranches. The main disadvantage to a system of this kind

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[2] EXTRAWATT, St. Jean sur la Lande, Quebec.
WELLINGTON WIND POWER, Wellington, Ontario;

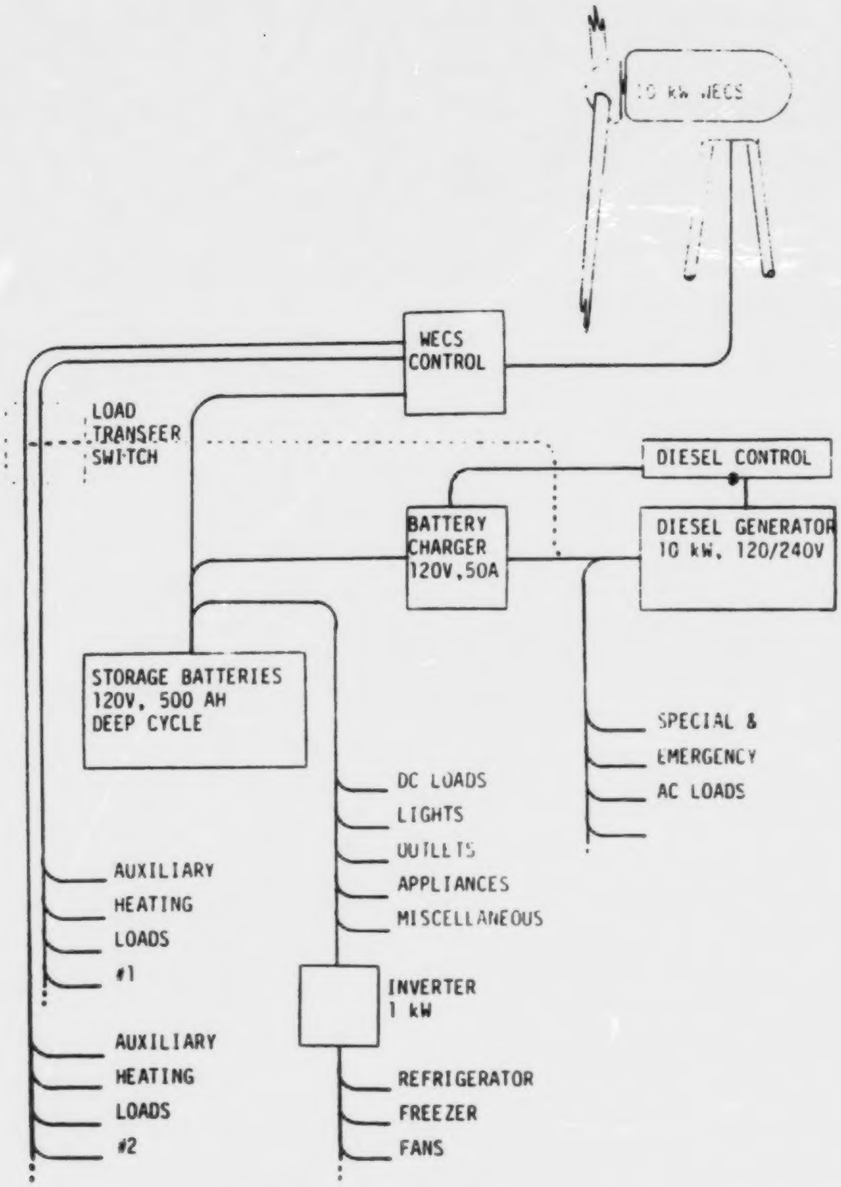

10 kW WECS
WECS CONTROL
LOAD TRANSFER SWITCH
DIESEL CONTROL
BATTERY CHARGER 120V,50A
DIESEL GENERATOR 10 kW, 120/240V
STORAGE BATTERIES 120V, 500 AH DEEP CYCLE
SPECIAL & EMERGENCY AC LOADS
DC LOADS
LIGHTS
OUTLETS
APPLIANCES
MISCELLANEOUS
AUXILIARY HEATING LOADS #1
INVERTER 1 kW
AUXILIARY HEATING LOADS #2
REFRIGERATOR
FREEZER
FANS

Figure 1 WECS/Diesel Cycle Charge Concept Diagram

is the necessity to operate the backup generator any time the batteries are at a state of low charge even if the load is significantly less than the average system capacity.

Since the above methods all suffered from serious constraints in the present application, the configuration known generally as a WECS/diesel cycle charge system, as described below, was chosen.

4. WECS/Diesel Cycle Charge System:

This configuration is a logical extrapolation of the stand alone system with battery storage and diesel or gasoline backup. The system involves the addition of a charging system to allow the diesel or gasoline generator to provide charging energy to the battery storage when inadequate wind is available to supply the energy. The loss of overall efficiency incurred because of battery storage. Usage efficiency is considerably less than that which would be incurred by variable load application of the diesel to supply the building's loads directly. The operating time of the diesel unit can also be reduced substantially.

3.5 Electrical Supply Configuration

The WECS/diesel cycle charge system supply configuration shown schematically in Figure 1 was determined through discussions with OMNR engineers and the regional park managers regarding the desired end use of the facility. Specifications for each of the principal components of the system are detailed in Appendix B. Although the WECS and controller is a complete unit, some additional equipment to integrate it with the diesel cycle charge system may be required depending upon the characteristics of the WECS controller. A load transfer switch on the auxiliary load lines would enable additional loading of the diesel generator during periods when the unit is operating at low output when the WECS is not operating. An interlock feature would prevent operation of the diesel when the WECS is operating and capable of charging the batteries.

The capacity of the battery storage has been selected as optimum for both stable and efficient operation of a 10 kW WECS and to allow for acceptable rates of discharge and cycling of the batteries. To enhance battery life expectancy under the assumed load conditions, cycle depth has been limited to 50 percent under normal operation.

The storage system and WECS has been sized to allow for 48 hours operation from fully charged batteries. Under the assumed condition of load demand and supply, it is estimated that the diesel generator will operate not more than 300 hours per year. The 10 kW diesel generator and associated charger will charge the batteries in less than six hours under the assumed conditions. A desirable feature of this configuration is that it will be unnecessary to operate the diesel overnight or during other periods when diesel engine noise may be objectionable.

Heat produced by the diesel generator when operating will be rejected to the diesel and battery storage shed or vented to the atmosphere during warmer months.

3.6 Selection of WECS

Although it is considered that a large market exists throughout the world for stand alone battery charging systems, there are few suppliers who have commercial systems available. During this investigation, the only two manufacturers identified who can supply complete systems in the 10 kW size category are Bergey Windpower of Norman, Oklahoma; and Jacobs Wind Electric of Minneopolis, Minnesota. There are several suppliers of smaller systems such as Dunlite of Australia; Hummingbird of California, USA; and Northwind in Vermont, USA. It has been found that there are no manufacturers of small WECS in Canada who can deliver proven and reliable systems that could meet the rigors of continuous operation in a location such as Winisk.

It is thus recommended that in spite of a desire to support Canadian manufacturers, an imported machine such as the Bergey or Jacobs must be chosen to enhance the probability of a successful demonstration project.

3.7 Wind Power Generated Energy Vs. Projected Loads

The energy available from a typical 10 kW windmill under the wind conditions of Winisk are shown in Appendix A. Often energy is available when it is not useful. For example, during December it is estimated that the windmill will generate 1532 kW.h. During one-third of the hours, it will generate an insignificant amount of power; for 12 percent of the time it will generate only 1 kW. As a result, it has been estimated that wind-generated power will satisfy 100 percent of the unoccupied electrical load and only 50 percent of the occupied electrical load. During the cold months, all of the remaining energy can be used to supply heating requirements. During the period from May to September, when heating loads are relatively low, all of the power from the wind will not be utilized. Thus in August, only 61 percent of the energy generated can be used.

4 COSTS

4.1 Capital Costs

For the reasons given in Section 3, the most appropriate diesel-powered system would be the cycle charge type. Hence, the incremental cost of adding wind power to the system amounts to the cost of the wind turbine only. The extra cost was estimated to be about $36,000 to $49,000 depending on final design detail.

4.2 Fuel Costs

The month-by-month energy costs shown in Table 2 were developed on the basis of fuel cost and combustion efficiency and do not reflect any charges for maintenance or replacement. As a result, no cost is shown for wind energy in this table while electricity is calculated at $0.735/kW.h based on $1.75/L of diesel fuel and a diesel consumption rate of 0.42 L/kW.h. Heating energy is calculated at $0.226/kW.h based on fuel at $1.75/L and an efficiency of 72 percent.

TABLE 2

WECS/DIESEL CYCLE CHARGE ANALYSIS	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
DAYS/MO.	31	28	31	30	31	30	31	31	30	31	30	31	
DAYS OCCUPIED	5	5	5	10	24	24	24	24	24	10	10	5	
DEGREE DAYS	1372	1212	1170	806	531	327	217	247	346	493	765	1188	8674
DEGREE DAYS/DAY	44	43	38	27	17	11	7	8	12	16	26	38	
ENERGY LOADS													
PRIORITY 1 (ELECTRICAL)													
UNOCCUPIED 3.4 kW.h/d(@75%)	118	104	118	91	32	27	32	32	27	95	91	118	884
OCCUPIED 12.4 kW.h/d(@75%)	83	83	83	165	397	397	397	397	397	165	165	83	2811
TOTAL kW.h ELECTRICAL	201	187	201	256	429	424	429	429	424	261	256	201	3695.
PRIORITY 2 (HEAT)													
WATER STORE(4.4-10.0C)kW.h	25	25	25	40						40	40	25	220
PRIORITY 3 (HEAT)													
SHED (5C,153W FREE,23W/C)	421	365	310	120							97	320	1632
PRIORITY 4 (HEAT)													
BLDG HEATING(132W/C)													
OCCUPIED(20C,500W FREE)kW.h	673	657	569	794	1166	693	396	470	741	447	751	579	7936
UNOCCUPIED(5C)	2575	2207	2038	879	92					193	792	2084	10860
DHW DEMAND 8kW.h/d OCCUPIED	40	40	40	80	192	192	192	192	192	80	80	40	1360
TOTAL kW.h HEAT DEMAND	3733	3294	2982	1913	1450	885	588	662	933	760	1760	3049	22009
GRAND TOTAL kW.h	3934	3481	3183	2169	1878	1309	1017	1090	1357	1021	2016	3250	25703
WECS kW.h AVAILABLE	1532	1046	939	1274	1891	1378	1022	1442	1500	1587	1785	1496	16892
WIND POWER SUPPLIES													
100% UNOCCUPIED ELECTRICAL	118	104	118	91	32	27	32	32	27	95	91	118	884
50% OCCUPIED ELECTRICAL	41	41	41	83	198	198	198	198	198	83	83	41	1405
HEATING LOADS	1373	900	780	1101	1450	885	588	662	933	760	1611	1337	12380
WECS kW.h USEFUL FRACTION	1532	1046	939	1274	1680	1110	818	892	1158	938	1785	1496	14669
COST WECS/DIESEL/BAT./OIL													
$ DIESEL ELECT.@$0.735/kW.h	30	30	30	61	146	146	146	146	146	61	61	30	1033
$ OIL HTG.LOADS @$0.226/kW.h	534	541	498	183	0	0	0	0	0	0	34	387	2176
TOTAL FUEL COST	564	571	528	244	146	146	146	146	146	61	95	417	3209
COST DIESEL/BAT./OIL													
$ ELECT ALL DIESEL	147	137	147	188	315	312	315	315	312	191	188	147	2716
$ OIL ALL HEATING LOADS	844	745	674	432	328	200	133	150	211	172	398	689	4974
TOTAL FUEL COST	991	882	821	620	643	512	448	465	522	363	586	836	7690

The annual fuel cost for the windmill/diesel/battery/oil heat system at landed fuel cost is estimated to be $3,209 versus a conventional diesel/battery/oil heat system which is estimated at $7,690. If the WECS/battery system could supply 75 percent of the occupied electrical load, the fuel cost for that system would be reduced by $470 to $2,739.

4.3 Monitoring

An essential component of the demonstration is monitoring of the system to confirm its performance and reliability. Monitoring of the system should also provide for transfer of information to groups, agencies, and organizations wishing to learn the technology. The task of monitoring the system is somewhat more complex than most WECS projects because of the intergrated operation of the system and load. Because the load and battery storage level are continuously variable, the performance or efficiency of the WECS will vary considerably with their condition. The cost to equip and operate a monitoring project will depend as well on the characteristics of the WECS selected.

A budgetary estimate for equipment and monitoring activity for one year is shown below.

		Cost	
Item	Description	Minimum	Maximum
1.	Anemometer and signal conditioning	$ 300	$ 1,000
2.	Voltage and current monitoring transducers	250	700
3.	Rental of 8-channel, 16-bit data logger	3,000	6,000
4.	Interpretation and analysis of data and preparation of project report	6,000	10,000
		$9,550	$17,700

This estimate includes the cost of two visits to the facility. It is assumed that a person resident in the area will be available to collect and load data recording tapes. Parameters measured for the system will include:

1. wind speed;
2. dc load current;
3. WECS battery charging current;
4. diesel battery charging current;
5. diesel kWh produced;
6. auxiliary load; and
7. battery voltage.

This information will allow calculation of energy output from the WECS and the diesel, energy used by the electric loads in the headquarter's building and shed, and the heating loads. Availability and maintenance requirements will be determined from a log book to be kept by the resident maintenance person.

4.4 Pre-installation Test of the Wind System

A pre-installation test of the system at an easily accessible and instrumented site is recommended. Experience with similar projects and technology has shown that technical problems are almost always encountered during the implementation and commissioning stages. The difficulties inherent in solving such problems at a remote site such as Winisk suggest it is impractical not to carry out at least preliminary tests at a more accessible location. It is, of course, evident that a significant cost would be incurred to carry out a comprehensive performance and reliability test. Also a delay of one year would result in project implementation. Typical costs to carry out a one-year test at the Atlantic Wind Test Site are detailed below:

o Transportation to AWTS and return to Toronto	$ 4,000
o Installation	3,000
o Commissioning	2,000
o Instrumentation	2,500
o Testing and pad rental	1,800
o Maintenance	3,000
o Reporting	3,000
	$35,000

This cost should not be considered as a component of the demonstration project cost but as an investment in information and technology development. Should it be considered desirable, it is possible that in light of increasing interest by other agencies, such as the National Research Council (NRC); Energy, Mines, and Resources (EM&R); and the Ontario Ministry of Energy (OME), funding to carry out this work in remote community systems may be available from them. It has been estimated that several hundred such projects could be developed if certain technical, economic, and institutional barriers were eliminated or reduced. Experience and knowledge of system performance and reliability would help to minimize the technical barriers.

5 INSTALLATION AND COMMISSIONING

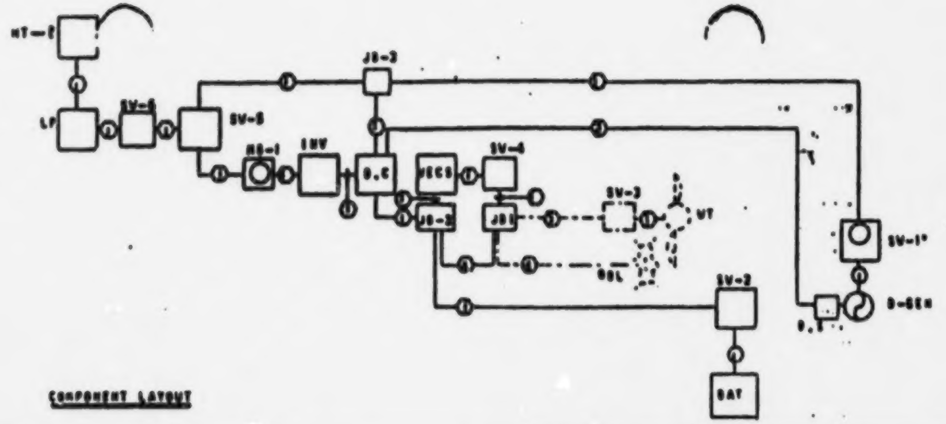
Following receipt of the design report, the system components were tendered, purchased, and installed by OMNR personnel. Installation was completed in September 1984. The system installed is shown schematically in Figure 2. After installation, several minor problems were encountered with the system. By January 1985, most of those had been resolved and commissioning of the system was possible.

5.1 First Visit

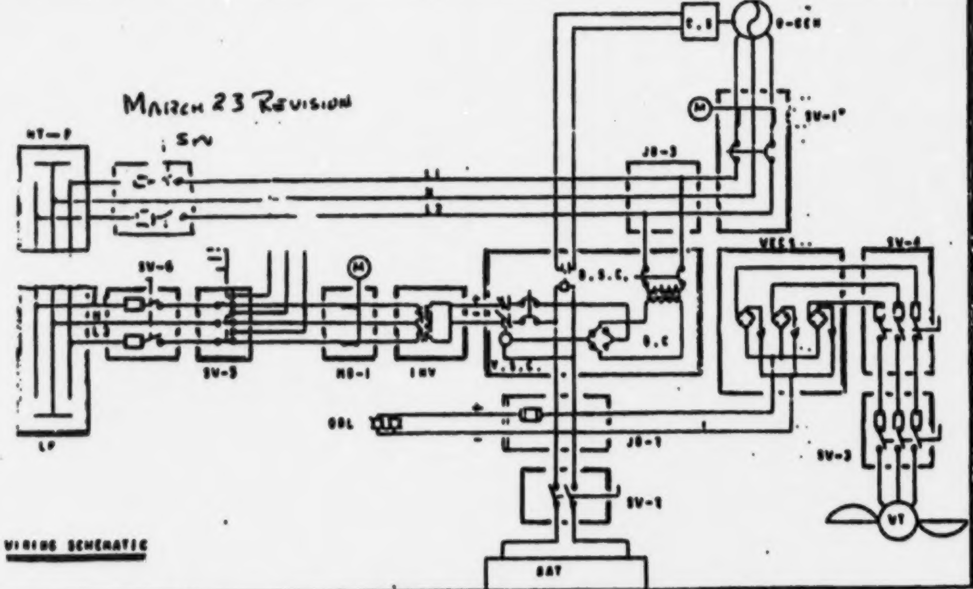
In March, a commissioning team travelled to Winisk to make final adjustments, inspect, and commission the system. Upon arrival, a general inspection of the installation revealed the following problems and conditions:

Wind turbine:

The wind turbine was not rotating although wind speeds at the time were within a range at which the rotor would be expected to be turning. Investigation from the ground revealed that the rotor was not in its usual position but had fallen forward and down so that the back surface of the alternator housing was touching the nacelle covers.



COMPONENT LAYOUT



WIRING SCHEMATIC

COMPONENT IDENTIFICATION

SYM.	DESCRIPTION
BAT	120 V DC STORAGE BATTERIES
B.C	BATTERY CHARGING UNIT C/W VOLTAGE SENSING RELAY (VSR) & DIESEL START CONTROL (DSC)
D.S	DIESEL STARTER
D-GEN	10 KW DIESEL GENERATOR 120/240 V AC 1 Ø 3 WIRE
D.S.C.	DIESEL CONTROL RELAY
HT-P	HEATING PANEL
INV	120 V DC INPUT 120/240 V AC OUTPUT INVERTER
JB-1	JUNCTION BOX (POWER FROM TURBINE
JB-2	JUNCTION BOX (120 V DC POWER)
JB-3	JUNCTION BOX (120/240 V AC-GENERATOR POWER)
LP-1	LIGHTING PANEL
MB-1	TYPE "S" METER BASE
OBL	OBSTRUCTION LIGHTS (TOWER MOUNTED)
*SW-1	COMBINATION METER SOCKET AND SERVICE SWITCH
SW-2	BATTERY DISCONNECT SWITCH
SW-3	WIND TURBINE TOWER SAFETY SWITCH
SW-4	WIND TURBINE SERVICE ENTRANCE SAFETYSWITCH
SW-5	3 POLE DOUBLE THROW SAFETY SWITCH
SW-6	DISTRIBUTION PANEL SAFETY SWITCH
V.S.C.	VOLTAGE SENSING RELAY
WECS	WIND ELECTRICAL CHARGING SYSTEM
WT	WIND TURBINE

WIRING CODE

①.	6/3 TYPE AC-90
②.	14/2 TYPE PJT
③.	1/0 TYPE USEI-90
④.	10/2 TYPE NMW-10

NOTES

1. * DENOTES ITEMS TO BE INSTALLED BY OTHERS.
2. DENOTES ITEMS REMOTE FROM ELECTRICAL CONTROL BUILDING.
3. THIS DRAWING IS A SIMPLIFIED OUTLINE OF THE PROJECT, THE OPERATOR SHOULD STUDY CAREFULLY THE OWNERS-OPERATION GUIDE FOR EACH COMPONENT PRIOR TO STARTING THE UNIT

Figure 2
March 23 Revision

					CUSTOMER MINISTRY OF NATURAL RESOURCES	L. MOORE POWER SYSTEMS P.O. BOX 771 - SHELBURNE; ONT; L0N-1S0	TITLE WINISK ALTERNATE ENERGY WIND PROJECT WIRING LAYOUT AND DETAILS
					PROJECT WINISK POWER PROJECT		DRN. L.C.M. FILE NO. LMS-011185-
					ORDER NO. SCALE N.T.S.		CHD. DWG NO 011185 REV 0
REVISION	BY	DATE	CHD.	APP.	UNIT NO. DATE 1/10/85		APP. JOB NO 1P-1-85

13a

The machine was lowered and inspection revealed that the main frame horizontal tube had failed at a point immediately behind the alternator mounting flange/tube weld. Slight damage occurred to both sections of the nacelle cover where the rotor chaffed against them. The failure to the tube was the result of fatigue. The material may have been defective or its resistance to fatigue reduced because of the adjacent welding and galvanizing. The machine was removed from the tower and placed in the OMNR building. A fuller inspection of the machine revealed no other damage.

It was also observed that the tower was bent at the flanges between the first and second tower sections. The bending appears to have been caused by lowering of the tower when sufficient hardpacked snow or ice was present to obstruct the tower frame laying down. Evidence that this had occurred is indicated by a dent in the tower at the lower end.

Inspection of the tower after lowering of the machine revealed cracks in the welds on each side of the flanged coupling. A review of the history of the installation indicates that the bending probably occurred during a lowering of the tower in January to make repair to tower obstruction lights.

The building that houses the diesel generator, batteries, and other electrical hardware was inspected and considered adequate but should be improved to incorporate the following:

1. positive ventilation for diesel engine combustion air;
2. a diesel exhaust vent tube higher up on the wall to avoid possible plugging by snowdrifts near the ground;
3. a smoke and gas detector to sense hazardous levels;
4. a vent system on the storage batteries;
5. relocation or shock mounting of the diesel control/monitoring system now on top of the generator;
6. identification of all switches, meters, and circuit breakers. A circuit diagram, operating instructions, and instructions for performance of basic maintenance and troubleshooting should be posted in the building;

7. a portable, rechargeable trouble light should be mounted in an easily accessible location in the shed;
8. a spares cabinet containing spare parts necessary to ensure that minor faults to the batteries, wind turbine, diesel engine, or other components do not cause the system to be out of service for extended periods. Tools necessary for replacement should be available in the shed;
9. an indication of battery voltage and/or a low battery voltage alarm should be placed in a conspicuous place in the office or lodge; and
10. insulating rubber mats should be placed on the floor around the battery bank to reduce electric shock hazard.

Electrical distribution circuits:

The electrical distribution system to the office and lodge was not configured exactly as recommended in the design report. The difference is related to the provision of electric heating. The design recommended that the electric heaters be supplied directly from the wind turbine when the batteries were fully charged or from the diesel when it was running to charge the batteries. As installed, the heaters are placed on the output of the inverter which draws energy from the storage batteries. Under these conditions the batteries will be cycled as frequently as twice each day during cold periods. This situation would seriously affect battery life.

During this visit, an additional distribution panel was installed to remove the heaters from the inverter and to place them only on the diesel. Although this will protect the batteries, it does not allow excess energy available from the wind turbine to be used for space heating. To enable heating to be supplied as planned, it will be necessary to incorporate an automatic transfer switch to select wind or diesel as source of the heating energy. A ballast tube or load controller in series with heating load may also be necessary to prevent over voltage on the heater in high winds.

Office and lodge:

Inspection of the building and renovation performed indicates that there are a number of matters still to attend to before it will meet the comfort and efficiency expectations that were discussed in the beginning with Ministry representatives.

In general, the deficiencies that should be reduced or eliminated are:

1. Doors should be insulated and well weatherstripped. Snow is actually blowing in around cracks.
2. Interior windows have been installed that are non-operable and do not allow for cleaning, repair, or adjustment to original external windows. Also there is no return or connection from the inner window frame to the outer frame. The inner casement should be made easily removable yet light. The window returns could be built when the windows are changed.
3. Electric water heating should be incorporated with the building heat. A simple method of draining all plumbing is necessary if the building is to be left unused for long periods.
4. The air-to-air heat exchanger can be mounted in the space above the existing hot water heater and vented into the kitchen and lounge areas. Inlets and outlets should be at least spaced about 4 metres.
5. A thermal scan of the inside of the building should be performed to identify any bad leaks or insulation problems.

Monitoring:

A monitoring program should be implemented as soon as possible to ensure that accurate information on performance is available both for general evaluation and as evidence and background in case of equipment malfunction. This project will have high visibility because of its unique wind/diesel cycle charge character and will undoubtedly have high demands for information in the next few years as others with similar remote energy supply situations learn of it.

5.2 Second Visit

In July 1985, a second visit to the site was made to replace and repair defective components and to install a control system to enable partial heating of the building by the wind turbine when the storage batteries have been fully charged.

Observations:

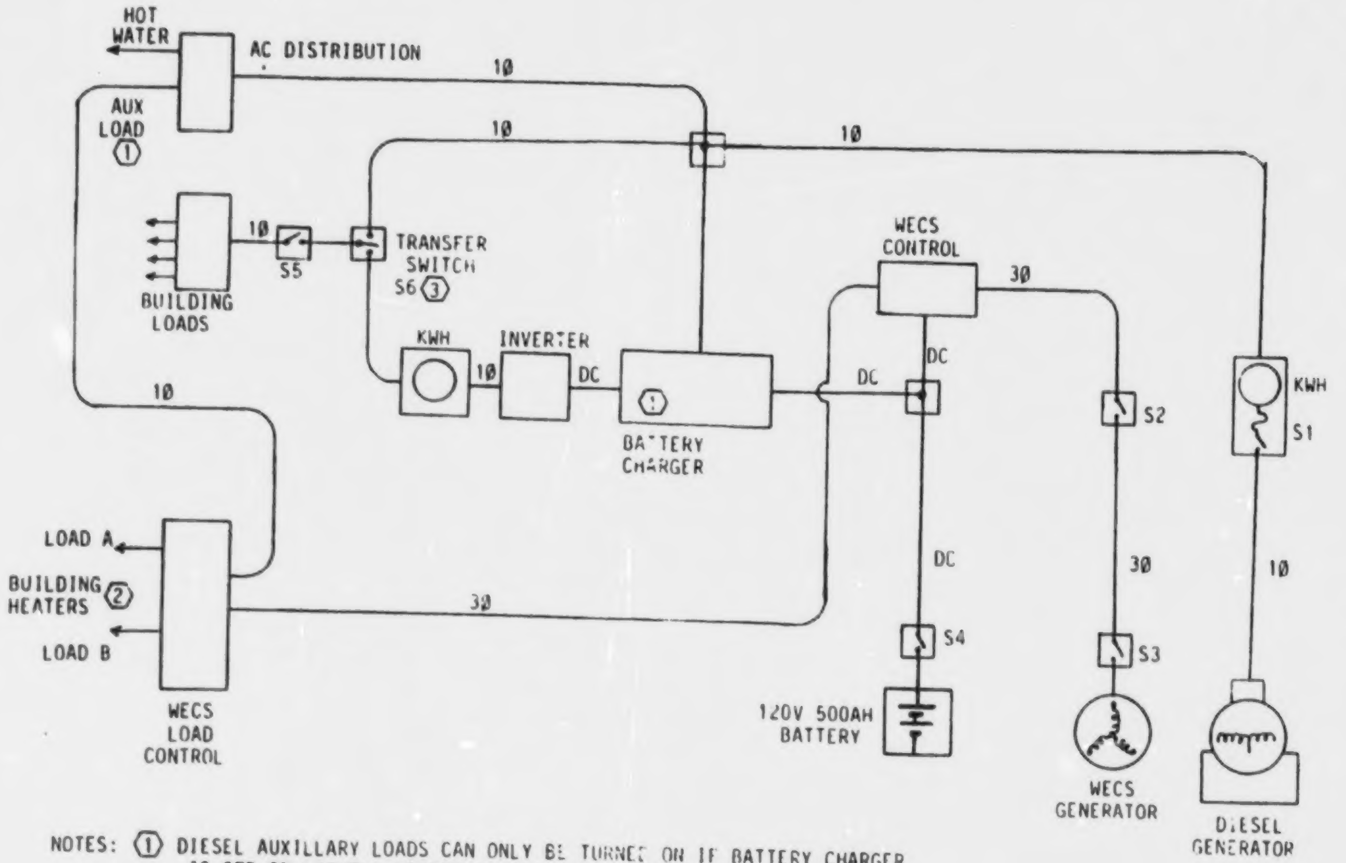
Upon arrival, the following observations were made:

1. Cracks in the tower sections at the flange welds were not as serious as they were thought to have been. Investigation with magnetic particles and dye penetrant equipment gave no indication that the cracks extended to the inside of the pipe.
2. It was observed that the diesel generator tripped off line when attempting to charge the batteries. Inspection of the machine revealed that one brush on the exciter was arcing under high output current conditions.

Work performed:

1. Cracks in the tower welds were repaired. Galvanizing was ground away and the cracks gouged and welded. The welded area was recovered with a spray galvanized finish.
2. The wind turbine main frame was replaced and the machine reassembled.
3. A dump load controller was installed in the equipment shed and connected to the Bergey controller and diesel output to enable either the output of the diesel or the direct a.c. output of the wind turbine to heat the headquarter building. A schematic design of the controller is shown in Figure 3.
4. The complete system was tested following completion of repairs and modifications. All equipment was found to be fully functional with the exception that the diesel generator was found to have a defective exciter brush. Arrangements were made by OMNR to obtain a replacement brush. Until replacement, the diesel would be run only in the manual mode. Considering that light usage of the building was anticipated, it was probable that the wind turbine would be able to maintain charge on the batteries until repairs were complete.

Figure 3


HOT WATER
AC DISTRIBUTION
AUX LOAD ①
1Ø
1Ø
1Ø
BUILDING LOADS
1Ø
S5
TRANSFER SWITCH S6 ③
WECS CONTROL
3Ø
KWH
1Ø
INVERTER
DC
BATTERY CHARGER
DC
DC
S2
KWH
S1
1Ø
LOAD A
BUILDING HEATERS ②
LOAD B
3Ø
WECS LOAD CONTROL
DC
3Ø
1Ø
S4
S3
120V 500AH BATTERY
WECS GENERATOR
DIESEL GENERATOR

NOTES:
① DIESEL AUXILLARY LOADS CAN ONLY BE TURNED ON IF BATTERY CHARGER IS OFF OR LIGHTLY LOADED (<25A)

② SEQUENCE OF SWITCHING OF LOAD A AND LOAD B CAN BE CHANGED BY SWAPPING CONTROL RELAYS C_3 AND C_4

③ TRANSFER LIGHTING LOADS TO DIESEL ONLY WHEN INVERTER OR BATTERIES EXHIBIT PROBLEMS

WINISK HEADQUARTERS
ELECTRICAL SYSTEM
GENERAL LAYOUT
JULY 1985

Figure 3.1

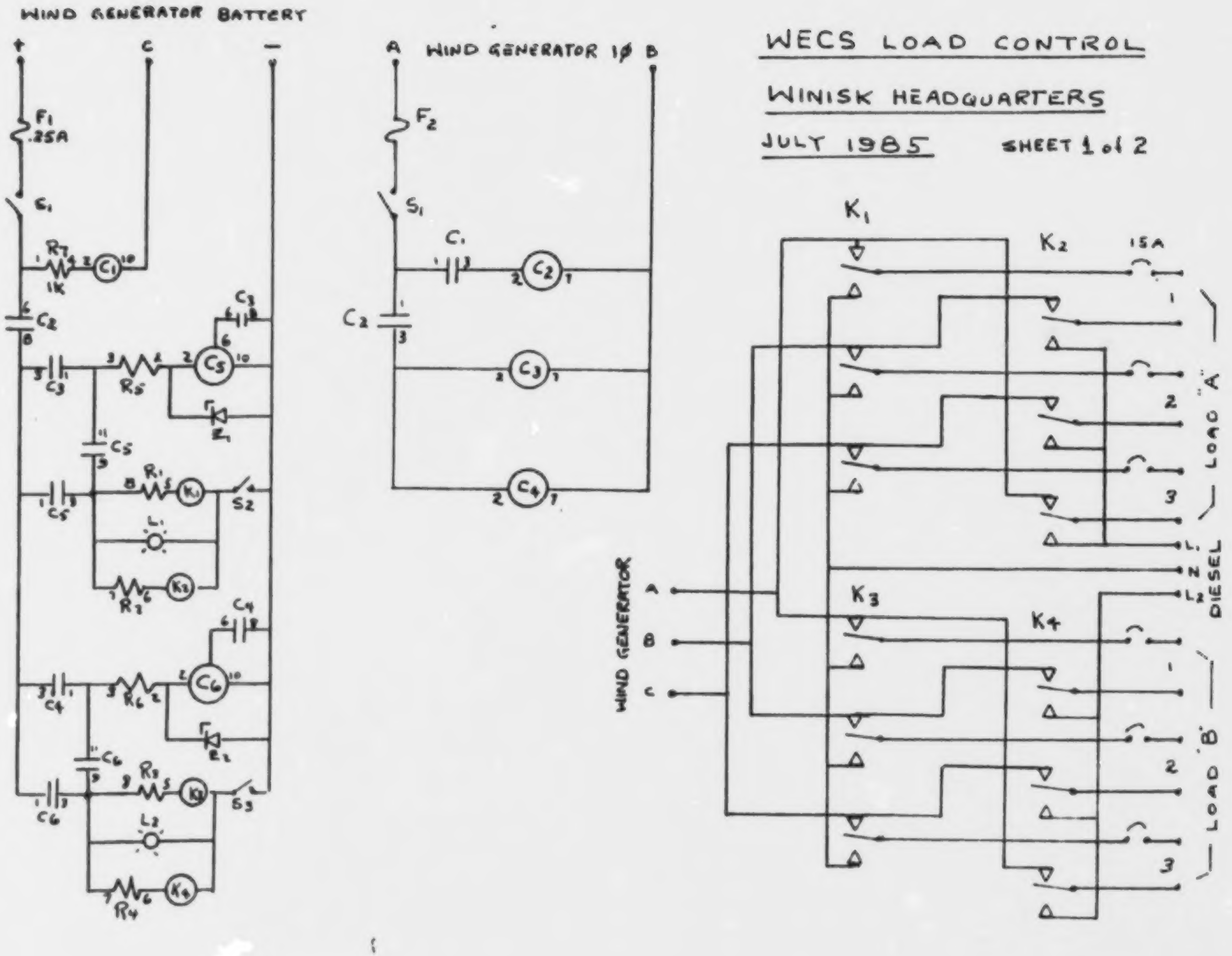

WECS LOAD CONTROL
WINISK HEADQUARTERS
JULY 1985
SHEET 1 of 2
WIND GENERATOR BATTERY
+
C
−
F1 .25A
S1
R7 1K
C1
C2
C3
R5
C5
Z1
R1
K1
S2
L1
R2
K2
C4
C6
R6
Z2
R3
K3
S3
L2
R4
K4
A
WIND GENERATOR 1Ø
B
F2
S1
C1
C2
C3
C4
K1
K2
15A
K3
K4
1
2
3
LOAD "A"
LOAD "B"
L1
N
L2
DIESEL
WIND GENERATOR
A
B
C

Figure 3.2

WECS LOAD CONTROL   WINISK HEADQUARTERS   JULY 1985   SHEET 2 of 2

C_1 DC		Control relay. Energized when Bergey VCS senses fully charged battery condition (141V)
C_2 C_2 C_3		Voltage Sensing Relays--Yellow Case
	C_2	Senses supply voltage, picks up at 100V, drops out at 95V, energizes C_3 and C_4
	C_3	Senses supply voltage, picks up at 115V, drops out at 100V, energizes time delay relay C_5
	C_4	Senses supply voltage, picks up at 140C, drops out at 110V, energizes time delay relay C_6
C_5 C_6		Time delay (on release-10 seconds)--White Case
	C_5	Picks up when C_3 energizes and closes K_1 K_2 Delays drop out of K_1 K_2 for 10 seconds after C_3 drops out.
	C_6	Picks up when C_4 energizes and closes K_3 K_4 Delays drop out of K_1 K_2 for 10 seconds after C_4 drops out.
K_1 K_2		Switches Load A from diesel generator to WECS
K_3 K_4		Switches Load B from diesel generator to WECS
R_5 Z_1: R_6 Z_2		Zener regulators to protect C_5, C_6 from overvoltage
R_1 R_2 R_3 R_4		Resistors to limit current to K_1, K_2, K_3, K_4 when batteries 125V+
R_7		Limits current through C_1 and Bergey switching circuit.
M_1		Measures output (AC) of Bergey when S_1 is on.

5. It was also noted that the vinyl tape protecting the leading edges of the wind turbine blades was detached and that the blades had longitudinal cracks extending from the tip inward about 0.2 m. The cracks are thought to be due to stress created during the auto furl pitching action. The manufacturer has been advised of this problem.

5.3 Subsequent Experience

During August, an inspection by OMNR staff of the site found that the wind turbine had fully charged the batteries to about 140 V and that all other systems appeared to be functional. Another inspection in September revealed that the inverter had failed and that some fuses were blown. Also the batteries were found in a completely discharged state as the result of the drain caused by navigational lights on the WECS tower. Because of blown fuses in the Bergey controller, the WECS was unable to charge the batteries. For reasons yet unknown, the diesel was also unable to charge the batteries through the dedicated charger, possibly because of defective brushes on the diesel generator.

6 CONCLUSION

The system is still not functional and complete information regarding the actual status of individual components is unavailable. It is possible that the only real difficulty is associated with the inverter failure and that replacement of fuses and adjustments to the battery charger will restore the system. Before this possibility can be confirmed however, it will be necessary to examine each component carefully and completely.

Discussion with regional OMNR personnel revealed that there is no doubt the inverter has failed.

Because of the integrated nature of the system, it will be necessary to insure that each component is fully repaired and tested prior to reactivation of the system. Following discussion with OMNR personnel, it seems advisable to remove each of the control components to Timmins or another accessible point for troubleshooting and testing. The diesel generator should be tested to determine whether it is able to supply full load to charge the batteries. The batteries should also be charged as soon as possible to minimize damage to them.

APPENDIX A

This appendix presents the annual and monthly estimates of energy production by a 10 kW WECS operating at Winisk. The calculations are based on mean monthly wind speeds obtained from meteorological data provided by AES for this analysis, the manufacturers published performance curve for the 10 kW Bergey EXCEL, and the assumption that the wind speed distribution conforms to the Rayleigh distribution

$$t = Te^{-\pi/4(v/\bar{v})^2}$$

where t = time in hours when the wind speed v is equal to or greater than v for an interval T during which the simple average wind speed is $\bar{v}$.

Effects of increases in air density at lower temperatures in winter months have not been included in the calculations. The effect of increased air density at -20°C is to increase the power output by about 13 percent from the value at 15°C. Because of compensating reductions in gearbox and other drive train efficiencies at lower temperatures, the effect has been overlooked to provide for a conservative estimate of WECS energy produced.

```
****************************************
*  RESOURCE VENTURES INCORPORATED      *
*                                      *        ANNUAL, ONE YEAR=
*  WECS ENERGY COMPUTATION     8/3/84  *           8760 HOURS
****************************************

   WECS MODEL:         BERGEY 10KW

   HUB HEIGHT =              100ft
                          19.60km/h
   V(avg) 33ft =          12.18mph,  V(avg) hub =     14.38mph

   a (height coef.) =        .15

   WEIBULL COEFs: k =        .79,    c =        2.00


     V [mph]  T [hrs]  Vi [mph] Ti [hrs]  P [KW]  E [KWHR]

        .00   8760.00       .50    46.26     .00         0
       1.00   8713.74      2.00   361.41     .00         0
       3.00   8352.32      4.00   678.48     .00         0
       5.00   7673.84      6.00   915.79     .00         0
       7.00   6758.05      8.00  1053.35     .20       211
       9.00   5704.70     10.00  1088.90     .30       327
      11.00   4615.80     12.00  1035.96    1.00      1036
      13.00   3579.84     14.00   918.60    1.80      1653
      15.00   2661.23     16.00   764.94    2.80      2142
      17.00   1896.29     18.00   601.11    4.20      2525
      19.00   1295.18     20.00   447.25    5.00      2236
      21.00    847.93     22.00   315.83    6.20      1958
      23.00    532.10     24.00   212.04    8.00      1696
      25.00    320.05     26.00   135.53    9.00      1220
      27.00    184.53     28.00    82.55   10.00       826
      29.00    101.98     30.00    47.96   10.00       480
      31.00     54.02     32.00    26.59   10.00       266
      33.00     27.43     34.00    14.08   10.00       141
      35.00     13.35     36.00     7.12    4.00        28
      37.00      6.23     38.00     3.44    4.00        14
      39.00      2.78     40.00     1.59    4.00         6
      41.00      1.19     42.00      .70    4.00         3
      43.00       .49     44.00      .30    4.00         1
      45.00       .19     46.00      .12    4.00         0
      47.00       .07     48.00      .05    4.00         0
      49.00       .03     50.00      .02    4.00         0
      51.00       .01     52.00      .01    4.00         0
      53.00       .00     54.00      .00    4.00         0
      55.00       .00     56.00      .00    4.00         0
      57.00       .00     58.00      .00    4.00         0
      59.00       .00     60.00      .00    4.00         0
      61.00       .00     62.00      .00    4.00         0
      63.00

*************************************************
*  ANNUAL ENERGY PRODUCED    [KWHR]=   16768.98  *
*************************************************
   MANUFACTURER'S CLAIM:    [KWHR] =   15000.00
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****************************************
*  RESOURCE VENTURES INCORPORATED       *
*                                       *        MONTH OF JANUARY
*  WECS ENERGY COMPUTATION      8/3/84 *              744 HOURS
****************************************

   WECS MODEL:          BERGEY 10KW

   HUB HEIGHT =               100ft
                            20.20km/h
   V(avg) 33ft =            12.55mph,  V(avg) hub =     14.82mph

   a (height coef.) =         .15

   WEIBULL COEFs: k =         .79,    c =        2.00


    V [mph]  T [hrs]  Vi [mph]  Ti [hrs]   P [KW]  E [KWHR]

        .00   744.00       .50      3.70      .00         0
       1.00   740.30      2.00     28.94      .00         0
       3.00   711.36      4.00     54.54      .00         0
       5.00   656.82      6.00     74.07      .00         0
       7.00   582.75      8.00     85.93      .20        17
       9.00   496.82     10.00     89.82      .30        27
      11.00   407.01     12.00     86.62     1.00        87
      13.00   320.39     14.00     78.04     1.80       140
      15.00   242.34     16.00     66.20     2.80       185
      17.00   176.14     18.00     53.12     4.20       223
      19.00   123.02     20.00     40.46     5.00       202
      21.00    82.56     22.00     29.32     6.20       182
      23.00    53.24     24.00     20.25     8.00       162
      25.00    32.99     26.00     13.35     9.00       120
      27.00    19.64     28.00      8.40    10.00        84
      29.00    11.24     30.00      5.06    10.00        51
      31.00     6.18     32.00      2.91    10.00        29
      33.00     3.26     34.00      1.61    10.00        16
      35.00     1.66     36.00       .85     4.00         3
      37.00      .81     38.00       .43     4.00         2
      39.00      .38     40.00       .21     4.00         1
      41.00      .17     42.00       .10     4.00         0
      43.00      .07     44.00       .04     4.00         0
      45.00      .03     46.00       .02     4.00         0
      47.00      .01     48.00       .01     4.00         0
      49.00      .00     50.00       .00     4.00         0
      51.00      .00     52.00       .00     4.00         0
      53.00      .00     54.00       .00     4.00         0
      55.00      .00     56.00       .00     4.00         0
      57.00      .00     58.00       .00     4.00         0
      59.00      .00     60.00       .00     4.00         0
      61.00      .00     62.00       .00     4.00         0
      63.00

**************************************************
*  ANNUAL ENERGY PRODUCED    [KWHR]=     1532.42  *
**************************************************
   MANUFACTURE'S CLAIM:    [KWHR] =     N/A
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****************************************
*  RESOURCE VENTURES INCORPORATED      *
*                                      *        MONTH OF FEBRUARY
*  WECS ENERGY COMPUTATION     8/3/84  *            672 HOURS
****************************************

   WECS MODEL:          BERGEY 10KW

   HUB HEIGHT =                100ft
                           18.10km/h
   V(avg) 33ft =           11.25mph,  V(avg) hub =      13.28mph

   a (height coef.) =         .15

   WEIBULL COEFs: k =         .79,    c =        2.00


    V [mph]  T [hrs]  Vi [mph] Ti [hrs]  P [KW]  E [KWHR]

        .00   672.00       .50     4.16      .00         0
       1.00   667.84      2.00    32.36      .00         0
       3.00   635.48      4.00    60.10      .00         0
       5.00   575.38      6.00    79.66      .00         0
       7.00   495.72      8.00    89.33      .20        18
       9.00   406.39     10.00    89.38      .30        27
      11.00   317.02     12.00    81.70     1.00        82
      13.00   235.31     14.00    69.11     1.80       124
      15.00   166.20     16.00    54.50     2.80       153
      17.00   111.70     18.00    40.27     4.20       169
      19.00    71.43     20.00    27.96     5.00       140
      21.00    43.47     22.00    18.30     6.20       113
      23.00    25.17     24.00    11.30     8.00        90
      25.00    13.87     26.00     6.60     9.00        59
      27.00     7.27     28.00     3.64    10.00        36
      29.00     3.63     30.00     1.91    10.00        19
      31.00     1.72     32.00      .94    10.00         9
      33.00      .78     34.00      .44    10.00         4
      35.00      .33     36.00      .20     4.00         1
      37.00      .14     38.00      .08     4.00         0
      39.00      .05     40.00      .03     4.00         0
      41.00      .02     42.00      .01     4.00         0
      43.00      .01     44.00      .00     4.00         0
      45.00      .00     46.00      .00     4.00         0
      47.00      .00     48.00      .00     4.00         0
      49.00      .00     50.00      .00     4.00         0
      51.00      .00     52.00      .00     4.00         0
      53.00      .00     54.00      .00     4.00         0
      55.00      .00     56.00      .00     4.00         0
      57.00      .00     58.00      .00     4.00         0
      59.00      .00     60.00      .00     4.00         0
      61.00      .00     62.00      .00     4.00         0
      63.00

**************************************************
*  ANNUAL ENERGY PRODUCED    [KWHR]=      1046.27  *
**************************************************
   MANUFACTURE'S CLAIM:    [KWHR] =      N/A
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*****************************************
*  RESOURCE VENTURES INCORPORATED       *
*                                       *          MONTH OF MARCH
*  WECS ENERGY COMPUTATION      8/3/84  *                744 HOURS
*****************************************

   WECS MODEL:          BERGEY 10KW

   HUB HEIGHT =               100ft
                            16.80km/h
   V(avg) 33ft =            10.44mph,  V(avg) hub =     12.33mph

   a (height coef.) =         .15

   WEIBULL COEFs: k =         .79,    c =       2.00


    V [mph]  T [hrs]  Vi [mph] Ti [hrs]  P [KW]  E [KWHR]

        .00   744.00       .50     5.34      .00        0
       1.00   738.66      2.00    41.39      .00        0
       3.00   697.27      4.00    75.94      .00        0
       5.00   621.33      6.00    98.69      .00        0
       7.00   522.64      8.00   107.65      .20       22
       9.00   414.99     10.00   103.94      .30       31
      11.00   311.05     12.00    90.97     1.00       91
      13.00   220.08     14.00    73.09     1.80      132
      15.00   147.00     16.00    54.32     2.80      152
      17.00    92.68     18.00    37.52     4.20      158
      19.00    55.16     20.00    24.17     5.00      121
      21.00    30.99     22.00    14.55     6.20       90
      23.00    16.43     24.00     8.21     8.00       66
      25.00     8.23     26.00     4.34     9.00       39
      27.00     3.89     28.00     2.15    10.00       22
      29.00     1.73     30.00     1.00    10.00       10
      31.00      .73     32.00      .44    10.00        4
      33.00      .29     34.00      .18    10.00        2
      35.00      .11     36.00      .07     4.00        0
      37.00      .04     38.00      .03     4.00        0
      39.00      .01     40.00      .01     4.00        0
      41.00      .00     42.00      .00     4.00        0
      43.00      .00     44.00      .00     4.00        0
      45.00      .00     46.00      .00     4.00        0
      47.00      .00     48.00      .00     4.00        0
      49.00      .00     50.00      .00     4.00        0
      51.00      .00     52.00      .00     4.00        0
      53.00      .00     54.00      .00     4.00        0
      55.00      .00     56.00      .00     4.00        0
      57.00      .00     58.00      .00     4.00        0
      59.00      .00     60.00      .00     4.00        0
      61.00      .00     62.00      .00     4.00        0
      63.00

***************************************************
*  ANNUAL ENERGY PRODUCED    [KWHR]=       938.94  *
***************************************************
   MANUFACTURE'S CLAIM:    [KWHR] =     N/A
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****************************************
*  RESOURCE VENTURES INCORPORATED      *
*                                      *          MONTH OF APRIL
*  WECS ENERGY COMPUTATION     8/3/84 *               720 HOURS
****************************************

   WECS MODEL:          BERGEY 10KW

   HUB HEIGHT =               100ft
                              19.00km/h
   V(avg) 33ft =              11.81mph,   V(avg) hub =     13.94mph

   a (height coef.) =         .15

   WEIBULL COEFs: k =         .79,     c =        2.00


    V [mph]  T [hrs]  Vi [mph] Ti [hrs]  P [KW]  E [KWHR]

         .00   720.00       .50     4.05      .00       0
        1.00   715.95      2.00    31.56      .00       0
        3.00   684.40      4.00    59.00      .00       0
        5.00   625.39      6.00    79.11      .00       0
        7.00   546.29      8.00    90.13      .20      18
        9.00   456.15     10.00    92.05      .30      28
       11.00   364.10     12.00    86.29     1.00      86
       13.00   277.82     14.00    75.18     1.80     135
       15.00   202.64     16.00    61.35     2.80     172
       17.00   141.29     18.00    47.12     4.20     198
       19.00    94.17     20.00    34.17     5.00     171
       21.00    60.00     22.00    23.46     6.20     145
       23.00    36.54     24.00    15.27     8.00     122
       25.00    21.27     26.00     9.43     9.00      85
       27.00    11.84     28.00     5.54    10.00      55
       29.00     6.30     30.00     3.10    10.00      31
       31.00     3.20     32.00     1.65    10.00      16
       33.00     1.56     34.00      .83    10.00       8
       35.0C      .72     36.00      .40     4.00       2
       37.00      .32     38.00      .18     4.00       1
       39.00      .14     40.00      .08     4.00       0
       41.00      .06     42.00      .03     4.00       0
       43.00      .02     44.00      .01     4.00       0
       45.00      .01     46.00      .01     4.00       0
       47.00      .00     48.00      .00     4.00       0
       49.00      .00     50.00      .00     4.00       0
       51.00      .00     52.00      .00     4.00       0
       53.00      .00     54.00      .00     4.00       0
       55.00      .00     56.00      .00     4.00       0
       57.00      .00     58.00      .00     4.00       0
       59.00      .00     60.00      .00     4.00       0
       61.00      .00     62.00      .00     4.00       0
       63.00

**************************************************
*  ANNUAL ENERGY PRODUCED    [KWHR]=      1274.31  *
**************************************************
   MANUFACTURE'S CLAIM:    [KWHR] =     N/A
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****************************************
*  RESOURCE VENTURES INCORPORATED      *
*                                      *          MONTH OF MAY
*  WECS ENERGY COMPUTATION     8/3/84  *               744 HOURS
****************************************

   WECS MODEL:        BERGEY 10KW

   HUB HEIGHT =             100ft
                           22.20km/h
   V(avg) 33ft =           13.79mph,  V(avg) hub =     16.29mph

   a (height coef.) =        .15

   WEIBULL COEFs: k =        .79,    c =        2.00


    V [mph]  T [hrs]  Vi [mph] Ti [hrs]  P [KW]  E [KWHR]

        .00   744.00       .50     3.06      .00         0
       1.00   740.94      2.00    24.07      .00         0
       3.00   716.87      4.00    45.81      .00         0
       5.00   671.06      6.00    63.29      .00         0
       7.00   607.77      8.00    75.20      .20        15
       9.00   532.57     10.00    81.05      .30        24
      11.00   451.52     12.00    81.15     1.00        81
      13.00   370.37     14.00    76.43     1.80       138
      15.00   293.94     16.00    68.24     2.80       191
      17.00   225.70     18.00    58.02     4.20       244
      19.00   167.67     20.00    47.15     5.00       236
      21.00   120.52     22.00    36.71     6.20       228
      23.00    83.82     24.00    27.42     8.00       219
      25.00    56.39     26.00    19.68     9.00       177
      27.00    36.71     28.00    13.59    10.00       136
      29.00    23.12     30.00     9.03    10.00        90
      31.00    14.09     32.00     5.78    10.00        58
      33.00     8.31     34.00     3.57    10.00        36
      35.00     4.74     36.00     2.12     4.00         8
      37.00     2.62     38.00     1.22     4.00         5
      39.00     1.40     40.00      .68     4.00         3
      41.00      .72     42.00      .36     4.00         1
      43.00      .36     44.00      .19     4.00         1
      45.00      .17     46.00      .09     4.00         0
      47.00      .08     48.00      .04     4.00         0
      49.00      .04     50.00      .02     4.00         0
      51.00      .02     52.00      .01     4.00         0
      53.00      .01     54.00      .00     4.00         0
      55.00      .00     56.00      .00     4.00         0
      57.00      .00     58.00      .00     4.00         0
      59.00      .00     60.00      .00     4.00         0
      61.00      .00     62.00      .00     4.00         0
      63.00

***********************************************
*  ANNUAL ENERGY PRODUCED   [KWHR]=    1891.39  *
***********************************************
   MANUFACTURE'S CLAIM:   [KWHR] =     N/A
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****************************************
*  RESOURCE VENTURES INCORPORATED      *
*                                      *         MONTH OF JUNE
*  WECS ENERGY COMPUTATION     8/3/84  *             720 HOURS
****************************************

   WECS MODEL:         BERGEY 10KW

   HUB HEIGHT =              100ft
                          19.60km/h
   V(avg) 33ft =          12.18mph,  V(avg) hub =     14.38mph

   a (height coef.) =        .15

   WEIBULL COEFs: k =        .79,    c =       2.00


    V [mph]  T [hrs]  Vi [mph] Ti [hrs]  P [KW]  E [KWHR]

        .00   720.00       .50     3.80       .00        0
       1.00   716.20      2.00    29.71       .00        0
       3.00   686.49      4.00    55.77       .00        0
       5.00   630.73      6.00    75.27       .00        0
       7.00   555.46      8.00    86.58       .20       17
       9.00   468.88     10.00    89.50       .30       27
      11.00   379.38     12.00    85.15      1.00       85
      13.00   294.23     14.00    75.50      1.80      136
      15.00   218.73     16.00    62.87      2.80      176
      17.00   155.86     18.00    49.41      4.20      208
      19.00   106.45     20.00    36.76      5.00      184
      21.00    69.69     22.00    25.96      6.20      161
      23.00    43.73     24.00    17.43      8.00      139
      25.00    26.31     26.00    11.14      9.00      100
      27.00    15.17     28.00     6.78     10.00       68
      29.00     8.38     30.00     3.94     10.00       39
      31.00     4.44     32.00     2.19     10.00       22
      33.00     2.25     34.00     1.16     10.00       12
      35.00     1.10     36.00      .59      4.00        2
      37.00      .51     38.00      .28      4.00        1
      39.00      .23     40.00      .13      4.00        1
      41.00      .10     42.00      .06      4.00        0
      43.00      .04     44.00      .02      4.00        0
      45.00      .02     46.00      .01      4.00        0
      47.00      .01     48.00      .00      4.00        0
      49.00      .00     50.00      .00      4.00        0
      51.00      .00     52.00      .00      4.00        0
      53.00      .00     54.00      .00      4.00        0
      55.00      .00     56.00      .00      4.00        0
      57.00      .00     58.00      .00      4.00        0
      59.00      .00     60.00      .00      4.00        0
      61.00      .00     62.00      .00      4.00        0
      63.00

**************************************************
*  ANNUAL ENERGY PRODUCED    [KWHR]=     1378.27  *
**************************************************
   MANUFACTURE'S CLAIM:   [KWHR] =     N/A
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****************************************
*  RESOURCE VENTURES INCORPORATED      *
*                                      *         MONTH OF JULY
*  WECS ENERGY COMPUTATION     8/3/84 *             744 HOURS
****************************************

   WECS MODEL:        BERGEY 10KW

   HUB HEIGHT =             100ft
                          17.30km/h
   V(avg) 33ft =          10.75mph,  V(avg) hub =     12.69mph

   a (height coef.) =       .15

   WEIBULL COEFs: k =       .79,    c =       2.00


    V [mph]  T [hrs]  Vi [mph] Ti [hrs]  P [KW]  E [KWHR]

        .00   744.00       .50     5.04      .00         0
       1.00   738.96      2.00    39.11      .00         0
       3.00   699.85      4.00    72.11      .00         0
       5.00   627.74      6.00    94.48      .00         0
       7.00   533.26      8.00   104.23      .20        21
       9.00   429.02     10.00   102.13      .30        31
      11.00   326.90     12.00    91.00     1.00        91
      13.00   235.90     14.00    74.68     1.80       134
      15.00   161.22     16.00    56.87     2.80       159
      17.00   104.36     18.00    40.38     4.20       170
      19.00    63.97     20.00    26.83     5.00       134
      21.00    37.14     22.00    16.72     6.20       104
      23.00    20.42     24.00     9.79     8.00        78
      25.00    10.63     26.00     5.39     9.00        49
      27.00     5.24     28.00     2.80    10.00        28
      29.00     2.45     30.00     1.37    10.00        14
      31.00     1.08     32.00      .63    10.00         6
      33.00      .45     34.00      .27    10.00         3
      35.0C      .18     36.00      .11     4.00         0
      37.00      .07     38.00      .04     4.00         0
      39.00      .02     40.00      .02     4.00         0
      41.00      .01     42.00      .01     4.00         0
      43.00      .00     44.00      .00     4.00         0
      45.00      .00     46.00      .00     4.00         0
      47.00      .00     48.00      .00     4.00         0
      49.00      .00     50.00      .00     4.00         0
      51.00      .00     52.00      .00     4.00         0
      53.00      .00     54.00      .00     4.00         0
      55.00      .00     56.00      .00     4.00         0
      57.00      .00     58.00      .00     4.00         0
      59.00      .00     60.00      .00     4.00         0
      61.00      .00     62.00      .00     4.00         0
      63.00

**************************************************
*  ANNUAL ENERGY PRODUCED    [KWHR]=      1021.72  *
**************************************************
   MANUFACTURE'S CLAIM:    [KWHR] =     N/A
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****************************************
*  RESOURCE VENTURES INCORPORATED      *
*                                      *          MONTH OF AUGUST
*  WECS ENERGY COMRUTATION     8/3/84 *               744 HOURS
****************************************

   WECS MODEL:        BERGEY 10KW

   HUB HEIGHT =             100ft
                           19.70km/h
   V(avg) 33ft =           12.24mph,  V(avg) hub =     14.46mph

   a (height coef.) =        .15

   WEIBULL COEFs: k =        .79,    c =       2.00


    V [mph]  T [hrs]  Vi [mph] Ti [hrs]  P [KW]  E [KWHR]

        .00   744.00       .50     3.89      .00        0
       1.00   740.11      2.00    30.39      .00        0
       3.00   709.72      4.00    57.09      .00        0
       5.00   652.63      6.00    77.14      .00        0
       7.00   575.48      8.00    88.86      .20       18
       9.00   486.62     10.00    92.04      .30       28
      11.00   394.58     12.00    87.77     1.00       88
      13.00   306.81     14.00    78.04     1.80      140
      15.00   228.77     16.00    65.20     2.80      183
      17.00   163.57     18.00    51.42     4.20      216
      19.00   112.15     20.00    38.41     5.00      192
      21.00    73.74     22.00    27.25     6.20      169
      23.00    46.49     24.00    18.38     8.00      147
      25.00    28.11     26.00    11.81     9.00      106
      27.00    16.30     28.00     7.24    10.00       72
      29.00     9.06     30.00     4.23    10.00       42
      31.00     4.83     32.00     2.36    10.00       24
      33.00     2.47     34.00     1.26    10.00       13
      35.00     1.21     36.00      .64     4.00        3
      37.00      .57     38.00      .31     4.00        1
      39.00      .26     40.00      .15     4.00        1
      41.00      .11     42.00      .06     4.00        0
      43.00      .05     44.00      .03     4.00        0
      45.00      .02     46.00      .01     4.00        0
      47.00      .01     48.00      .00     4.00        0
      49.00      .00     50.00      .00     4.00        0
      51.00      .00     52.00      .00     4.00        0
      53.00      .00     54.00      .00     4.00        0
      55.00      .00     56.00      .00     4.00        0
      57.00      .00     58.00      .00     4.00        0
      59.00      .00     60.00      .00     4.00        0
      61.00      .00     62.00      .00     4.00        0
      63.00

 ************************************************
 *  ANNUAL ENERGY PRODUCED   [KWHR]=     1442.21 *
 ************************************************
    MANUFACTURE'S CLAIM:   [KWHR] =    N/A
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****************************************
*  RESOURCE VENTURES INCORPORATED      *
*                                      *          MONTH OF SEPTEMBER
*  WECS ENERGY COMPUTATION     8/3/84 *                720 HOURS
****************************************

   WECS MODEL:         BERGEY 10KW

   HUB HEIGHT =              100ft
                           20.30km/h
   V(avg) 33ft =           12.61mph,  V(avg) hub =     14.90mph

   a (height coef.) =        .15

   WEIBULL COEFs: k =        .79,    c =       2.00


    V [mph]  T [hrs]  Vi [mph] Ti [hrs]  P [KW]  E [KWHR]

        .00   720.00       .50      3.55      .00        0
       1.00   716.45      2.00     27.74      .00        0
       3.00   688.71      4.00     52.30      .00        0
       5.00   636.41      6.00     71.10      .00        0
       7.00   565.31      8.00     82.60      .20       17
       9.00   482.71     10.00     86.49      .30       26
      11.00   396.22     12.00     83.59     1.00       84
      13.00   312.63     14.00     75.50     1.80      136
      15.00   237.13     16.00     64.23     2.80      180
      17.00   172.89     18.00     51.71     4.20      217
      19.00   121.18     20.00     39.53     5.00      198
      21.00    81.64     22.00     28.77     6.20      178
      23.00    52.88     24.00     19.96     8.00      160
      25.00    32.92     26.00     13.22     9.00      119
      27.00    19.70     28.00      8.37    10.00       84
      29.00    11.33     30.00      5.07    10.00       51
      31.00     6.27     32.00      2.94    10.00       29
      33.00     3.33     34.00      1.63    10.00       16
      35.0C     1.70     36.00       .87     4.00        3
      37.00      .84     38.00       .44     4.00        2
      39.00      .40     40.00       .22     4.00        1
      41.00      .18     42.00       .10     4.00        0
      43.00      .08     44.00       .05     4.00        0
      45.00      .03     46.00       .02     4.00        0
      47.00      .01     48.00       .01     4.00        0
      49.00      .01     50.00       .00     4.00        0
      51.00      .00     52.00       .00     4.00        0
      53.00      .00     54.00       .00     4.00        0
      55.00      .00     56.00       .00     4.00        0
      57.00      .00     58.00       .00     4.00        0
      59.00      .00     60.00       .00     4.00        0
      61.00      .00     62.00       .00     4.00        0
      63.00

*****************************************************
*  ANNUAL ENERGY PRODUCED    [KWHR]=       1500.47  *
*****************************************************
   MANUFACTURE'S CLAIM:    [KWHR] =      N/A
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****************************************
*  RESOURCE VENTURES INCORPORATED      *
*                                      *        MONTH OF OCTOBER
*  WECS ENERGY COMPUTATION      8/3/84 *              744 HOURS
****************************************

   WECS MODEL:       BERGEY 10KW

   HUB HEIGHT =            100ft
                         20.50km/h
   V(avg) 33ft =         12.74mph,  V(avg) hub =    15.04mph

   a (height coef.) =      .15

   WEIBULL COEFs: k =      .79,   c =       2.00


    V [mph]  T [hrs]  Vi [mph] Ti [hrs]  P [KW]  E [KWHR]

          .00   744.00      .50     3.59      .00        0
         1.00   740.41     2.00    28.12      .00        0
         3.00   712.28     4.00    53.08      .00        0
         5.00   659.20     6.00    72.30      .00        0
         7.00   586.90     8.00    84.22      .20       17
         9.00   502.69    10.00    88.49      .30       27
        11.00   414.20    12.00    85.87     1.00       86
        13.00   328.33    14.00    77.96     1.80      140
        15.00   250.37    16.00    66.70     2.80      187
        17.00   183.67    18.00    54.05     4.20      227
        19.00   129.63    20.00    41.62     5.00      208
        21.00    88.01    22.00    30.53     6.20      189
        23.00    57.48    24.00    21.36     8.00      171
        25.00    36.12    26.00    14.29     9.00      129
        27.00    21.83    28.00     9.14    10.00       91
        29.00    12.70    30.00     5.59    10.00       56
        31.00     7.10    32.00     3.28    10.00       33
        33.00     3.82    34.00     1.84    10.00       18
        35.00     1.98    36.00      .99     4.00        4
        37.00      .99    38.00      .51     4.00        2
        39.00      .47    40.00      .25     4.00        1
        41.00      .22    42.00      .12     4.00        0
        43.00      .10    44.00      .06     4.00        0
        45.00      .04    46.00      .02     4.00        0
        47.00      .02    48.00      .01     4.00        0
        49.00      .01    50.00      .00     4.00        0
        51.00      .00    52.00      .00     4.00        0
        53.00      .00    54.00      .00     4.00        0
        55.00      .00    56.00      .00     4.00        0
        57.00      .00    58.00      .00     4.00        0
        59.00      .00    60.00      .00     4.00        0
        61.00      .00    62.00      .00     4.00        0
        63.00

***************************************************
*  ANNUAL ENERGY PRODUCED   [KWHR]=      1586.62  *
***************************************************
   MANUFACTURE'S CLAIM:   [KWHR] =     N/A
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****************************************
*  RESOURCE VENTURES INCORPORATED      *
*                                      *        MONTH OF NOVEMBER
*  WECS ENERGY COMPUTATION      8/3/84 *              744 HOURS
****************************************

   WECS MODEL:          BERGEY 10KW

   HUB HEIGHT =              100ft
                           21.60km/h
   V(avg) 33ft =           13.42mph,  V(avg) hub =    15.85mph

   a (height coef.) =        .15

   WEIBULL COEFs: k =        .79,   c =       2.00


    V [mph]  T [hrs]  Vi [mph] Ti [hrs]  P [KW]  E [KWHR]

        .00   744.00       .50     3.24     .00         0
       1.00   740.76      2.00    25.39     .00         0
       3.00   715.37      4.00    48.20     .00         0
       5.00   667.17      6.00    66.28     .00         0
       7.00   600.88      8.00    78.25     .20        16
       9.00   522.64     10.00    83.64     .30        25
      11.00   438.99     12.00    82.90    1.00        83
      13.00   356.10     14.00    77.14    1.80       139
      15.00   278.96     16.00    67.92    2.80       190
      17.00   211.03     18.00    56.86    4.20       239
      19.00   154.18     20.00    45.40    5.00       227
      21.00   108.78     22.00    34.66    6.20       215
      23.00    74.12     24.00    25.35    8.00       203
      25.00    48.77     26.00    17.78    9.00       160
      27.00    30.99     28.00    11.97   10.00       120
      29.00    19.02     30.00     7.75   10.00        77
      31.00    11.27     32.00     4.82   10.00        48
      33.00     6.45     34.00     2.89   10.00        29
      35.00     3.56     36.00     1.66    4.00         7
      37.00     1.90     38.00      .92    4.00         4
      39.00      .98     40.00      .49    4.00         2
      41.00      .49     42.00      .25    4.00         1
      43.00      .23     44.00      .13    4.00         1
      45.00      .11     46.00      .06    4.00         0
      47.00      .05     48.00      .03    4.00         0
      49.00      .02     50.00      .01    4.00         0
      51.00      .01     52.00      .01    4.00         0
      53.00      .00     54.00      .00    4.00         0
      55.00      .00     56.00      .00    4.00         0
      57.00      .00     58.00      .00    4.00         0
      59.00      .00     60.00      .00    4.00         0
      61.00      .00     62.00      .00    4.00         0
      63.00

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*  ANNUAL ENERGY PRODUCED    [KWHR]=     1784.67  *
*************************************************
   MANUFACTURE'S CLAIM:   [KWHR] =      N/A
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*****************************************
*  RESOURCE VENTURES INCORPORATED       *
*                                       *      MONTH OF DECEMBER
*  WECS ENERGY COMPUTATION      8/3/84  *          744 HOURS
*****************************************

   WECS MODEL:          BERGEY 10KW

   HUB HEIGHT =               100ft
                            20.00km/h
   V(avg) 33ft =            12.43mph,  V(avg) hub =     14.68mph

   a (height coef.) =        .15

   WEIBULL COEFs: k =        .79,    c =        2.00


    V [mph]  T [hrs]  Vi [mph] Ti [hrs]  P [KW]  E [KWHR]

        .00   744.00       .50     3.77      .00         0
       1.00   740.23      2.00    29.51      .00         0
       3.00   710.72      4.00    55.54      .00         0
       5.00   655.18      6.00    75.28      .00         0
       7.00   579.90      8.00    87.09      .20        17
       9.00   492.81     10.00    90.71      .30        27
      11.00   402.10     12.00    87.09     1.00        87
      13.00   315.01     14.00    78.07     1.80       141
      15.00   236.94     16.00    65.83     2.80       184
      17.00   171.12     18.00    52.46     4.20       220
      19.00   118.65     20.00    39.66     5.00       198
      21.00    78.99     22.00    28.50     6.20       177
      23.00    50.49     24.00    19.50     8.00       156
      25.00    30.99     26.00    12.73     9.00       115
      27.00    18.26     28.00     7.93    10.00        79
      29.00    10.33     30.00     4.72    10.00        47
      31.00     5.61     32.00     2.69    10.00        27
      33.00     2.93     34.00     1.46    10.00        15
      35.00     1.47     36.00      .76     4.00         3
      37.00      .70     38.00      .38     4.00         2
      39.00      .33     40.00      .18     4.00         1
      41.00      .14     42.00      .08     4.00         0
      43.00      .06     44.00      .04     4.00         0
      45.00      .03     46.00      .02     4.00         0
      47.00      .01     48.00      .01     4.00         0
      49.00      .00     50.00      .00     4.00         0
      51.00      .00     52.00      .00     4.00         0
      53.00      .00     54.00      .00     4.00         0
      55.00      .00     56.00      .00     4.00         0
      57.00      .00     58.00      .00     4.00         0
      59.00      .00     60.00      .00     4.00         0
      61.00      .00     62.00      .00     4.00         0
      63.00

**************************************************
*  ANNUAL ENERGY PRODUCED    [KWHR]=      1496.30  *
**************************************************
   MANUFACTURE'S CLAIM:    [KWHR] =      N/A
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APPENDIX B

1. Battery Charger Requirement

Type: Constant voltage

Rating: 240 V 1Ø, 60 Hz 50 A

Style: Floor or wall mount

Features: Meters for output volts and output amps

Controls: Circuit breakers out and in, low and high voltage alarm and contacts for diesel control.

Input: 10 kW, 120/240 V, 1Ø diesel generator

2. Diesel Generator Requirement

Rating:
- 10 kW output
- 120/240 1Ø, 60 Hz, 1800 rpm
- Continuous duty
- Air cooled

Controls: Auto start and shut off, over temperature and vibration shut off.

Features:
- Loss of load shutdown
- Output volts and amperes

Fuel: Cold weather diesel fuel

Typical Use: 6 hour battery charging cycles 50 times per year

Life Expectancy: 10 years before major overhaul

3. WECS Requirement

Type:	Horizontal axis wind turbine battery charging system with auxiliary load control
Tower:	100' self erecting
Rating:	10 kW @ 20 mph
Output Voltage:	120 V nominal
Storage Battery Rating:	500 AH (48 hour rate)
Annual kWh at 12 mph (33' elevation):	15,000 kW.h miminum
Control:	- Passive yaw - High wind speed shutdown - Overspeed protection - Manual shut down - Automatic unattended operation
Operational Characteristics:	- Start up wind speed - 10 mph maximum - Cut out wind speed - 50 mph minimum - Survival wind speed - 120 mph
System Design Life:	20 years minimum
Maintenance Requirement:	Yearly inspection and lubrication
Notes:	The machine will be located at a remote site in Northern Ontario having an annual average wind speed (Rayleigh distributed) of 12.0 mph at 33 feet. Temperatures of -40°C are typical in winter. The WECS and battery system is to supply electrical energy and supplemental heat to a residential office complex requiring up to 385 kW.h/month to meet electrical needs. The system should carry a minimum warranty of 1 year from installation on all parts and labour and 5 years parts only on major components of the rotor, gear train generator and controls. A list of recommended spares is to be provided. The system is to be a production unit backed by reputable service. Documentation for installation, operation, maintenance and troubleshooting is to be provided.

4. Storage Battery Requirement

Nominal Voltage:	120 V
Type:	Deep cycle
Application:	Cycle charge power for residential application
Charging Source:	10 kW wind turbine and 10 kW diesel generator
Discharge Rates:	210 AH in 48 hours
Maximum Cycle Depth at 0°C:	50% final charge (190 volts/cell)
Mininum Operating Temperature:	0°C
Maximum Operating Temperature:	25°C
Maximum Discharge Current:	37A
Maximum Average Discharge Current (48 Hour):	4.4A
Life Expectancy:	10 years, 1500 cycles

DEMONSTRATION PROGRAMS/OPERATIONAL EXPERIENCE

ATLANTIC WIND TEST SITE

1985 CANWEA CONFERENCE

Carl Brothers, AWTS

INTRODUCTION

The Atlantic Wind Test Site (AWTS) located at North Cape, Prince Edward Island was established by the governments of Prince Edward Island and Canada to assist in the research and development of Canada's wind energy technology and equipment.

The AWTS was designed and developed by the Institute of Man and Resources (IMR) under the 1977 Canada-P.E.I. Agreement on Renewable Energy and was officially opened for business in July 1980. The facility is managed by IMR under the terms of a ten-year operating agreement with the National Research Council (NRC). The site is operated by Resource Ventures Incorporated (RVI), a wholly owned subsidiary of IMR.

The AWTS is funded from paying clients of the site's resources and from NRC's Division of Energy through a contribution agreement which provides up to $200,000 per year to offset operating costs. This ten-year agreement started in 1981 and is managed by a group of five directors who meet quarterly to review performance and provide input for future operations.

FACILITIES

The site is located at the extreme north-eastern tip of P.E.I. and consists of 180 acres of flat terrain bordered by low 6-15 metre cliffs. It is exposed through 300° to the sea and is subjected to weather conditions typical of a marine area. It experiences moderately high levels of corrosion and considerable salt spray.

Annual average windspeeds of 6.25 m/s (14 mph) are consistently higher in winter and prevail from the northwest in winter and southwest in summer.

The earth-sheltered lab provides an operations centre for site activities. It houses office space, living accommodations for occasional use, an electronics lab, and a data processing centre. A mechanical shop is located near the main building. The site is serviced by a 600 V, 3-Ø distribution line running the length of the site to provide power to each test pad.

PROJECTS

Presently there are five projects active at the site:

Anemometer Comparison Project

The Atmospheric Environment Service (AES) has contracted the AWTS to monitor the performance of a number of anemometers over a one-year period to compare performance and reliability. Included in the comparison were AES standard anemometers and anemometers from Bendix, R.M. Young, Athabasca Research, Maximum, Climet, and Vector as well as wind data loggers from Indal Technologies, Natural Power, Northumbrian Energy Workshop, and Second Wind.

The preliminary report has been completed and will be submitted to AES later this month. The report will be available through AES by early next year.

Northwind L916 Reliability Test

Health and Welfare Canada have purchased a Northwind L916 for installation at their Hall Beach, NWT, nursing station. The machine has a two-blade, 9-m diameter rotor, mounted on a 70-ft timber pole. It is a downwind machine with passive pitch control. It is connected single-phase to the grid. Before installing it in Hall Beach, it has been undergoing reliability tests at AWTS for two years. Some initial problems with the generator have been resolved and the manufacturer has made recent modifications to the pitch control system. The unit will continue to be tested for the winter. If it performs satisfactorily, it will be installed at Hall Beach next summer.

CSA WECS Performance Standard Verification Test

The CSA performance standard for wind turbines, which has been under development for several years, has been issued in draft form for review and comment prior to being accepted as standard.

The AWTS plans to use two machines on the site to conduct the proposed performance test prior to final publication of the standard.

A 7.5 kW Indal VAWT will be tested using the general performance standard and a 1 kW Bergey will be used to carry out the battery charging section of the performance test.

Project Aquilo (Aquilo; roman-the Northwind

Aquilo, an Indal Technologies Incorporated 500 kW VAWT has been undergoing tests at the AWTS for two years.

There are some interesting mechanical aspects to the unit. The rotor, 37 m X 27m, rotates @ 45 rpm driving 2 - 350 Hp induction motors through a single step spur gear speed increaser. The large bull gear for the speed increaser is flexibly coupled to the rotor by a jaw/pin universal arrangement and rotates in a hydraulic bearing in the base of the unit. Hydraulic oil is pumped between the stub shaft and the bull gear to lift the entire rotor off a set of brake pads located under the bull gear. A hydraulic piston and cylinder which acts as a lower thrust bearing when in operation is depressurized for shut down and the rotor simply falls on the brake pads.

Net energy production of the machine has been much less than expected since erection due to a series of problems that have been slow to resolve.

During the summer of 1985, following replacement of the machine's guy cables and other control system improvements, it seemed that good reliability had at last been acheived and the machine finally started meeting performance expectations.

From early September to mid-November, the machine ran with nearly 100 percent availibility and set records for energy production in October with over 80,000 kWh being produced.

On November 15, the unit suffered a blade failure at the upper strut connection of one blade. The unit has since been taken down and is awaiting further action by Indal Technologies.

Adecon

Adecon Energy Corporation of Weston has developed a low-cost, intermediate-sized VAWT for NRC. The prototype has been installed at AWTS since early 1985.

The free-standing unit is an unique design and offers a number of innovative concepts.

The external frame, consisting of lattice work trusses fabricated of angle sections, eliminates the need for guy cables and elevates the rotor to increase energy capture. Eliminating guy cables results in reduced loading on the bearings, torque tube, and foundations and substantially reduces cost.

The aluminum blades consist of multiple extrusions bonded by aircraft adhesive to reduce weight. The blade weighs over about 3.3 kg/m.

The rotor, which has an operating speed of 45 rpm, sits directly on a 40:1 two-stage speed increaser which drives a 125 kW induction motor/generator. Braking is acheived by a disc brake on the high speed shaft.

Adecon staff have, over the past several months, operated the machine up through the power range to about 70 percent of full power. They are presently completing tests on a new braking system prior to testing at full power.

Findings to date indicate that performance and stress levels are as predicted and important resonant frequencies are avoided at operating speeds.

During the erection and operation of this unit some potential problems have been uncovered and design modifications are underway to eliminate these prior to installation of the first production machine.

FUTURE ACTIVITIES

In the future, we expect that AWTS will continue to operate, at least until the expiry of our initial operating agreement (1991). The recent government restraint has certainly affected us. However, despite the termination of NRC's role in wind energy research and development, we are confident that our present agreement will remain in place as long as the site contribes to the wind energy community in Canada.

Specific activities we will be involved in are:

- A study for EMR to assess cost reduction opportunities for small and large WECS.
- The AES anemometer study which is in the final report stage. We hope to continue some additional work on this subject.
- Further testing and development on both the Adecon and Indal units on site.
- Participation in the development of a wind diesel test system on the site.

CONCLUSIONS

At AWTS, we have recovered much of our optimism that seemed to disappear with the announced cutbacks last year. Wind energy around the world has made some dramatic gains in the past few years. As Canadian manufacturers overcome their problems, we expect that our products will be competitive in terms of cost and reliability with any units in the world. We think this will happen in the next few years and are excited about participating in the process.

PERFORMANCE AND STRUCTURAL DYNAMIC TESTING OF THE INDAL TECHNOLOGIES 500 kW VAWT

P.J. PENNA

NATIONAL RESEARCH COUNCIL OF CANADA
LOW SPEED AERODYNAMICS LABORATORY
BUILDING M-2, MONTREAL ROAD
OTTAWA, ONTARIO
K1A 0R6

ABSTRACT

In mid-1983, the National Research Council of Canada (NRCC) purchased a 500 kW, Series 6400 Vertical Axis Wind Turbine (VAWT) from INDAL TECHNOLOGIES INC. of Mississauga, Ontario. The turbine was installed at the Atlantic Wind Test Site (AWTS) in Prince Edward Island under the direction and sponsorship of NRCC. The testing and evaluation of the turbine has been given the name "Project Aquilo".

The turbine is fully instrumented in order to measure its power performance and structural stresses.

A detailed description of the instrumentation and data acquisition system is the subject of another NRCC report and so only an overview of these items will be given in this report.

The power output vs. wind speed curve for the turbine is being determined using the International Energy Agency's "Recommended Practices for Wind Turbine Testing and Evaluation: No. 1 Power Performance Testing". The results obtained thus far are presented.

Spectral analysis of the dynamic rotor stress signals has been carried out using a Fast Fourier Transform computer program. By examining the magnitude of the spectral peaks it was possible to conclude that the rotor had a natural frequency which was excited at three times per turn. Structural de-tuning was carried out on the rotor in order to reduce this near-resonant condition.

1.0 INTRODUCTION

In mid-1983, the National Research Council of Canada (NRCC) purchased a 500 kW, Series 6400 Vertical Axis Wind Turbine (VAWT) from INDAL TECHNOLOGIES INC. of Mississauga, Ontario, Canada. The turbine was installed at the Atlantic Wind Test Site (AWTS) in Prince Edward Island in September to December, 1983 and its commissioning tests were carried out by INDAL TECHNOLOGIES in early 1984. Under the direction and sponsorship of NRCC, AWTS is responsible for monitoring and maintaining the turbine as well as the instrumentation and data acquisition system. INDAL TECHNOLOGIES has provided warranty support during the commissioning and acceptance testing. The testing and evaluation of the turbine has been given the name "Project Aquilo".

2.0 DESCRIPTION OF THE TURBINE

A photograph of the turbine at the Atlantic Wind Test Site is presented as Figure 1. The Series 6400 VAWT is a Darrieus type having two blades of extruded aluminium with a chord of 0.737 m and a NACA 0015 aerofoil section. The rotor has a height of 36.6 m and an equatorial diameter of 25.2 m. There are two horizontal struts on the rotor at 7.3 m from each rotor bearing which provide additional stiffness to the blades. The guy wire support system consists of three pairs of guy wires, independently terminated at the anchor point and the upper rotor bearing. Two 261 kW induction motor/generators are used in order to increase the conversion efficiency over the nominal 500 kW range of the turbine. Further details of the rotor support system, transmission and fail safe brake are presented in References (1), (2) and (3).

3.0 INSTRUMENTATION AND DATA ACQUISITION

A general overview of the instrumentation for the turbine is as follows:

a) strain gauges on the blades at 38 locations,
b) strain gauges on the central column at 2 locations,
c) motor/generator shaft speed and torque transducers,
d) electrical power output transducers,
e) guy tension load cells on each guy wire,
f) anemometers and direction sensors at 76.2 m north-east and 76.2 m south-west of the turbine at the turbine's equatorial height, and
g) ambient air temperature and barometric pressure sensors.

The strain gauge locations on the rotor are shown in Figure 2. At each blade station (A1, A3, A4, etc.) strain gauges are located at the leading edge (L.E.), trailing edge (T.E.), inner neutral axis (I.N.) and outer neutral axis (O.N.), except the B4 station, where strain gauges are located at the leading edge and trailing edge only. On the central column, strain gauges are located at the mid-point in such a manner that one set monitors the bending of the column out of the plane of the rotor (RCO) and one set monitors the bending of the column in the plane of the rotor (RCI).

A Hewlett-Packard HP-1000, A-700, computer was installed at the AWTS for the sole purpose of acquiring all of the test data from the turbine. Software developed by Sandia National Laboratories was extensively modified by DMR and Associates (a management consulting firm) to meet NRCC's requirements. The software has the capability to carry out the "method of bins" analysis, carry out spectral analysis of time series measurements, and provide a graphical display of measurements or analysed results.

In addition, AWTS continuously monitors the status of the turbine with the site's computerized data acquisition system. AWTS has also used the method of bins analysis on these records to produce a power output vs. wind speed curve for the turbine. These binned results are discussed in 4.0 below.

A detailed description of the instrumentation, signal conditioning and data acquisition system is given in References (4) and (5).

4.0 POWER PERFORMANCE

Figure 3 shows a comparison of the turbine's theoretical and measured electrical power output as a function of wind speed. The theoretical curve was calculated by INDAL TECHNOLOGIES using the CARDAA computer program, Reference (6), which is based on the "double multiple stream tube momentum theory" and the known efficiencies of the drive train and induction generators.

In the double multiple streamtube theory, the surface of the body of revolution formed by the turbine rotor is divided into horizontal slices and vertical sectors, thus defining as many as 720 four-sided elements. The aerodynamic loads on each blade element are computed using an iterative procedure based on the actuator-disk theory. Furthermore, the upwind and downwind faces of the rotor are analysed separately. The ambient wind speed for each downwind blade element is calculated from the wake velocity of the corresponding upwind element in the streamtube. In this way, the complete shaft power curve can be calculated for a range of wind speeds.

The experimental data were collected using the procedures outlined in the International Energy Agency's Recommended Practices for Wind Turbine Testing and Evaluation: Part 1, Power Performance Testing. One of the requirements of this standard which has the most impact on the test procedures and data gathering is the necessity to take 10 minute averages of the power output and wind speed in order to obtain a single data point for use in the method of bins analysis. This results in a longer overall data collection period than that required by other standards which specify shorter averaging times. Furthermore, since the number of hours in the year with high wind speeds is not large, then it is difficult to obtain a large number of data points at high wind speeds (i.e. greater than 15 m/s). There will tend to be less reliability in the high wind speed data because of this constraint.

The constant speed Darrieus turbine relies on progressive blade stalling in order to limit the power output at high wind speeds. Therefore, a correction for air density may be applied to all power outputs (including those at high wind speeds) because active power limiting devices are not used by the turbine. Accordingly, all power outputs are corrected to the standard air density of 1.225 kg/m^3.

There are two sets of experimental data presented in Figure 3. Both sets were collected and binned by the AWTS computer system. (At the time of this writing, the method of bins analysis had not been completed on all of the recorded data which have been archived by the HP-1000, A-700 computer system). The disagreement between the two data sets at wind speeds greater than 10 m/s is of concern. A possible explanation is that between the time that the two data sets were recorded, relocation of each generator's power factor capacitor banks, in the power output circuit, may have caused the power transducers for each generator to be affected in some adverse manner. The cause of this discrepancy in the data is presently under investigation by AWTS and NRCC.

In addition, the figure indicates that the data are approximately 55 kW below the theoretical prediction at wind speeds greater than 15 m/s. However, AWTS has recorded an individual day of high wind speed data whose binned results were only 20 to 30 kW below the prediction. (That day's results have been included in the second data set, of course, but have been averaged with other, equally valid results to produce the final plot). A re-examination of the archived, once-per-second samples is probably required before this disagreement between theory and experiment can be categorized as a flaw in the theoretical prediction method.

5.0 STRUCTURAL DYNAMIC RESPONSE

As discussed in References (7), (8) and (9), the excitation forces on the Darrieus rotor are produced by cyclic aerodynamic loads plus inertia loads which result from blade deformations in a rotating frame of reference. Furthermore, there are usually many modes of vibration which are excited by these loads, but of these, the "butterfly" mode (or some variant of it) is often found to be the one with the largest contribution to the total blade deformation and stress. The butterfly mode appears as bending of both blades at the struts in the lead-lag direction but in such a manner that both blades deflect to the same side of the rotor at the same time. Reference (8) discusses the aerodynamic origin of this type of response and shows that it will be excited at frequencies which are odd multiples of the rotational frequency of the rotor (especially at once and three times the rotational frequency). In order to control the magnitude of the deflections caused by the butterfly mode, the struts were designed with coil springs and friction pad dampers at their central members which intersect the hollow central column. Reference (10) discusses the rotor's structural response and presents stress measurements taken when this strut damper mechanism was operational.

In April, 1985 it was discovered that the strut damper mechanism had failed and that a complete re-design would be required. INDAL TECHNOLOGIES decided instead to lock the strut damper mechanism such that no movement was allowed at the central column. Based on structural dynamic computer predictions, Reference (9), INDAL TECHNOLOGIES expected the rotor to have a natural frequency very close to three times per turn with the struts locked. Indeed, analysis of the stress data collected after the struts were locked showed that the lead-lag stresses at the struts were much larger at all wind speeds. This was primarly due to an increase in the three times per turn component of the stress waveform. INDAL TECHNOLOGIES decided that this undesirable situation would be eliminated by adding additional mass to the blades at the equatorial area of their span. This was accomplished by injecting 400 pounds of fine glass beads into the hollows of each blade.

The goal of this modification was to reduce the natural frequencies of the blades such that the resonant condition at three times per turn would be eliminated. (It should be noted that the blades already contained 400 pounds of glass beads when the turbine began operation with the strut damper mechanism operational. The additional mass now meant that each blade had 800 pounds of glass beads in its hollows at the equator region).

Analysis of the stress data collected after the blades were injected with the additional mass, shows that the modification was successful. Figure 4 is an example of spectral analysis of the stress waveform at the A5 L.E. location when the turbine was operating in winds of 15 to 20 m/s. As can be seen from the figure the dominant frequencies are at 0.75 Hz and 2.25 Hz which correspond to once and three times the rotational frequency of the rotor, respectively (1P and 3P). Also present, but at much smaller amplitudes, are spectral peaks at 1.5 Hz (2P), 3.0 Hz (4P), 3.75 Hz (5P) and 4.5 Hz (6P). Finally, the spectral peak at 2.1 Hz is confirmation of the modification's success. This spectral peak appears because the rotor now has a natural frequency at 2.1 Hz, instead of the undesirable value of 2.25 Hz (3P), as mentioned above. It is probably being excited by random fluctuations in the wind and by the fact that it remains close enough to the 3P excitation forces to be affected by them.

With regard to the flatwise bending of the blades, Figure 5 is the same analysis carried out at the same time on the stress waveform at the A5 I.N. location. Here the amplitudes of the 1P and 3P spectral peaks are only a fraction of what they are at the leading edge. From this comparison and from similar comparisons of spectra at other locations, one concludes that most of the structural response of the rotor is an out-of-plane, lead-lag deflection of the blades.

6.0 CONCLUSIONS

At the time of this writing, it is not possible to conclude that the experimentally determined power output data are a true representation of the turbine's performance at wind speeds greater than 11 m/s. Since individual averages which agree with the theoretical prediction have been observed at wind speeds greater than 15 m/s, then there is sufficient reason to investigate all of the power output data for possible errors.

Monitoring of the turbine's dynamic stresses using strain gauges has proved to be valuable diagnostic tool. Furthermore, the combination of good instrumentation and powerful computing capability has provided this test program with the analysed data needed to make a satisfactory evaluation of the turbine's structural response.

7.0 ACKNOWLEDGEMENTS

The author has relied heavily on the cooperation and individual skills of the following in the preparation of the analysed results for this report:

- the staff of the Atlantic Wind Test Site,
- J. Keller and T. Onno of NRCC, and
- C. DeSchiffart of DMR and Associates

Their contribution is gratefully acknowledged.

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10) P.J. Penna, The DAF-INDAL LTD. SERIES 6400 VAWT at the Atlantic Wind Test Site: Performance and Structural Dynamic Test Data. Presented at INTERSOL 85, International Solar Energy Society Congress, Montreal Quebec, June 23-29, 1985.

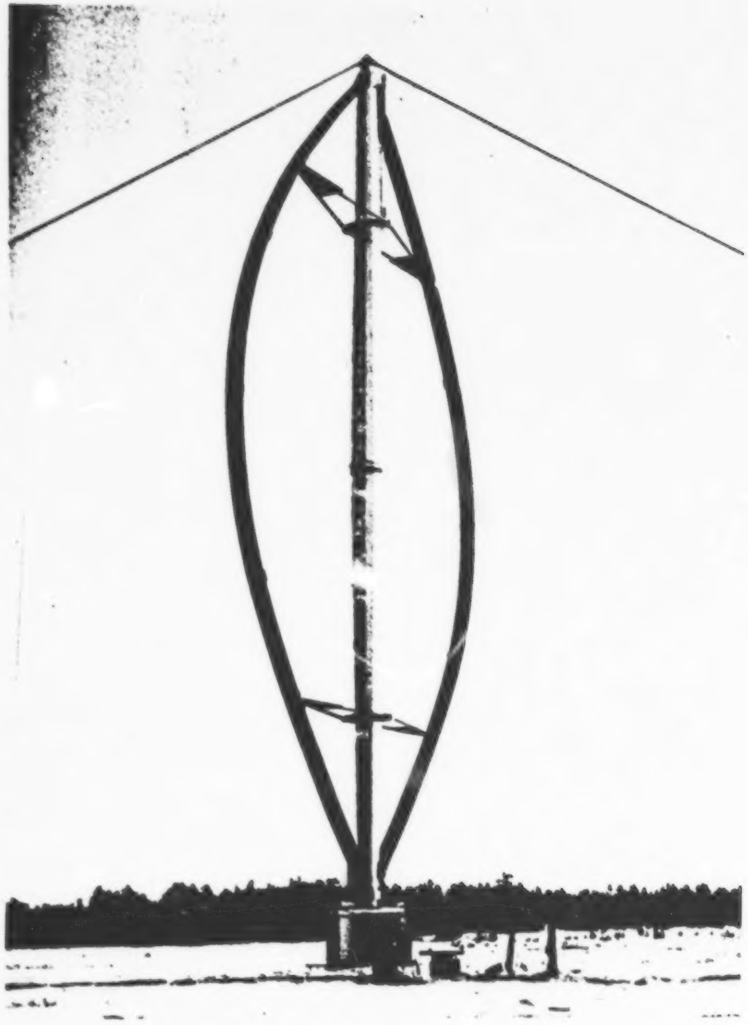


FIGURE 1: THE INDAL TECHNOLOGIES 500 kW VAWT AT THE ATLANTIC WIND TEST SITE

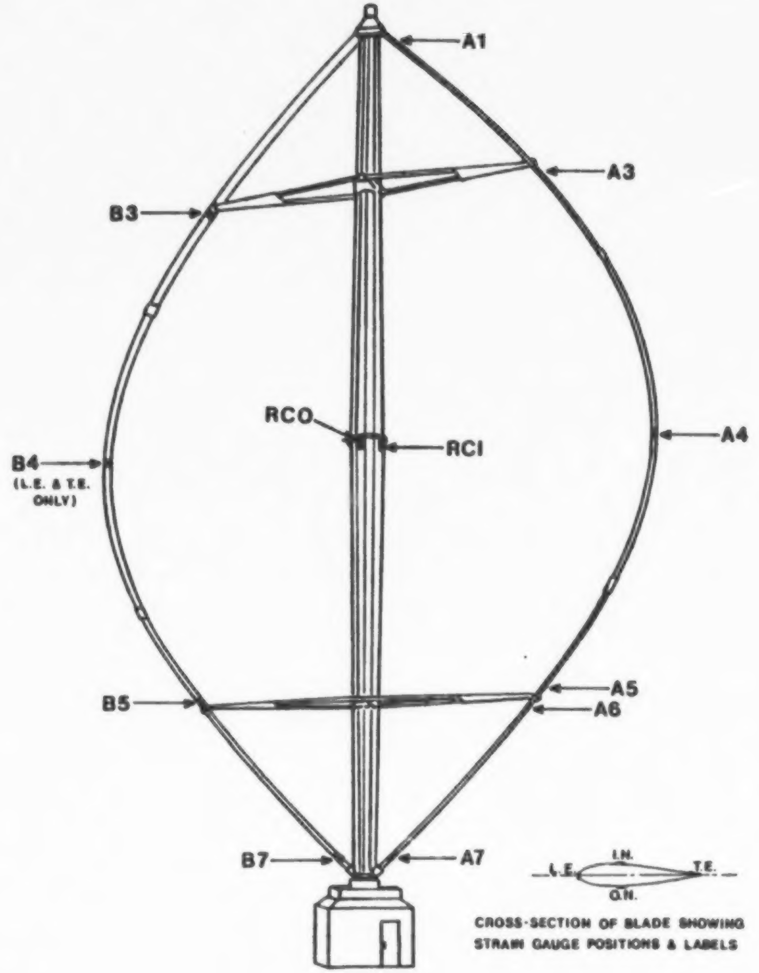
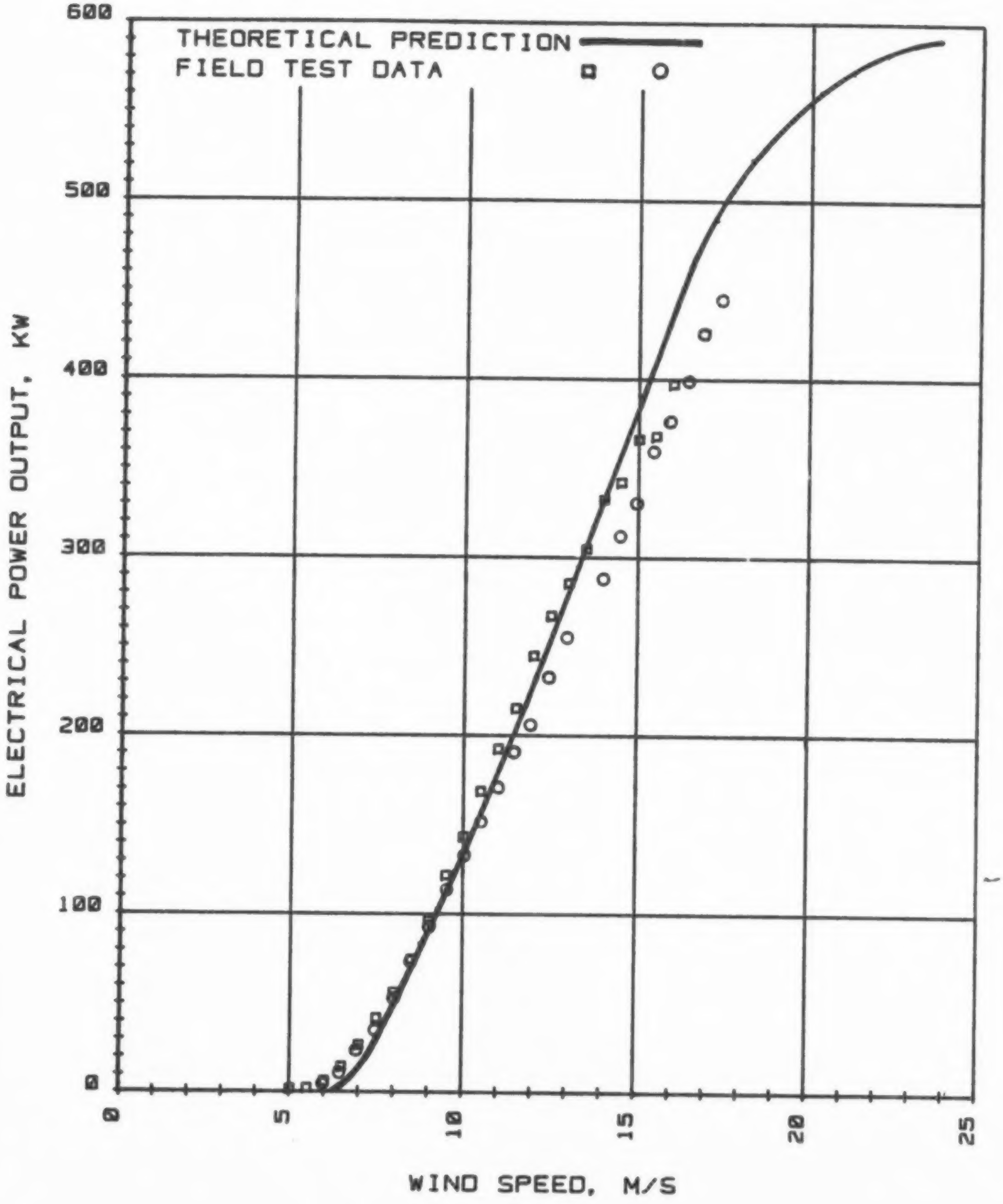

A1
A3
B3
RCO
RCI
A4
B4
(L.E. & T.E. ONLY)
A5
A6
B5
B7
A7
L.E.
I.N.
T.E.
O.N.
CROSS-SECTION OF BLADE SHOWING STRAIN GAUGE POSITIONS & LABELS

FIGURE 2: STRAIN GAUGE LOCATIONS ON THE ROTOR



□ - DATA COLLECTED JAN. - MAR. ,1985

o - DATA COLLECTED SEPT. - NOV. ,1985

FIGURE 3: TURBINE ELECTRICAL POWER OUTPUT
VS. WIND SPEED

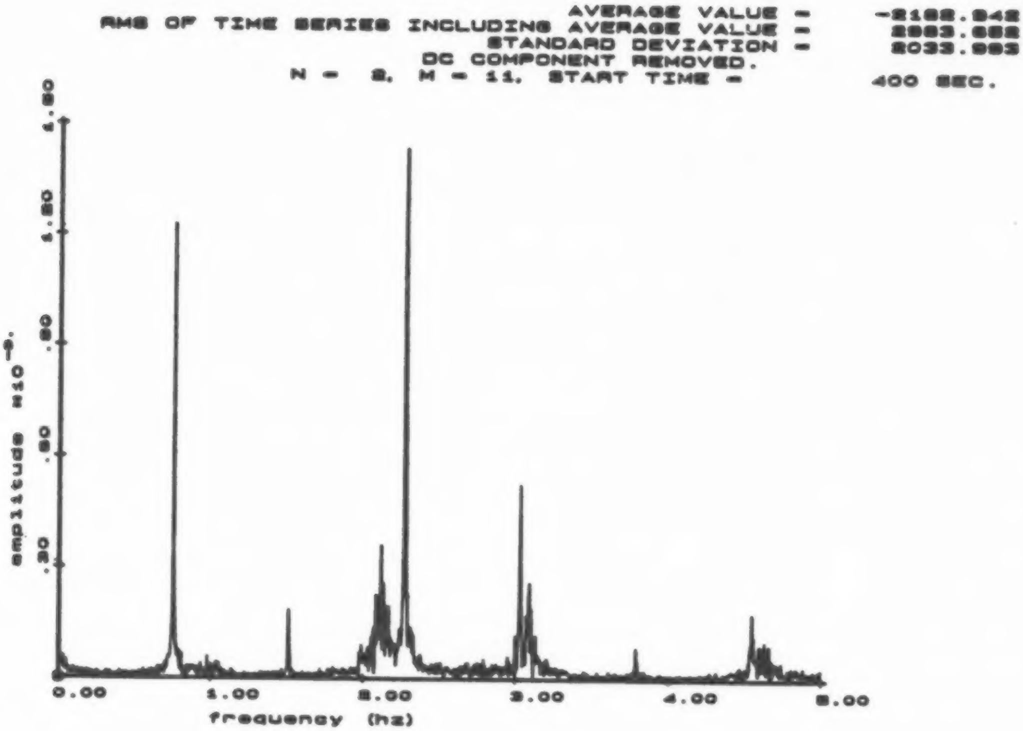


FIGURE 4: SPECTRAL ANALYSIS OF THE BLADE STRESS WAVEFORM AT THE A5 LEADING EDGE LOCATION

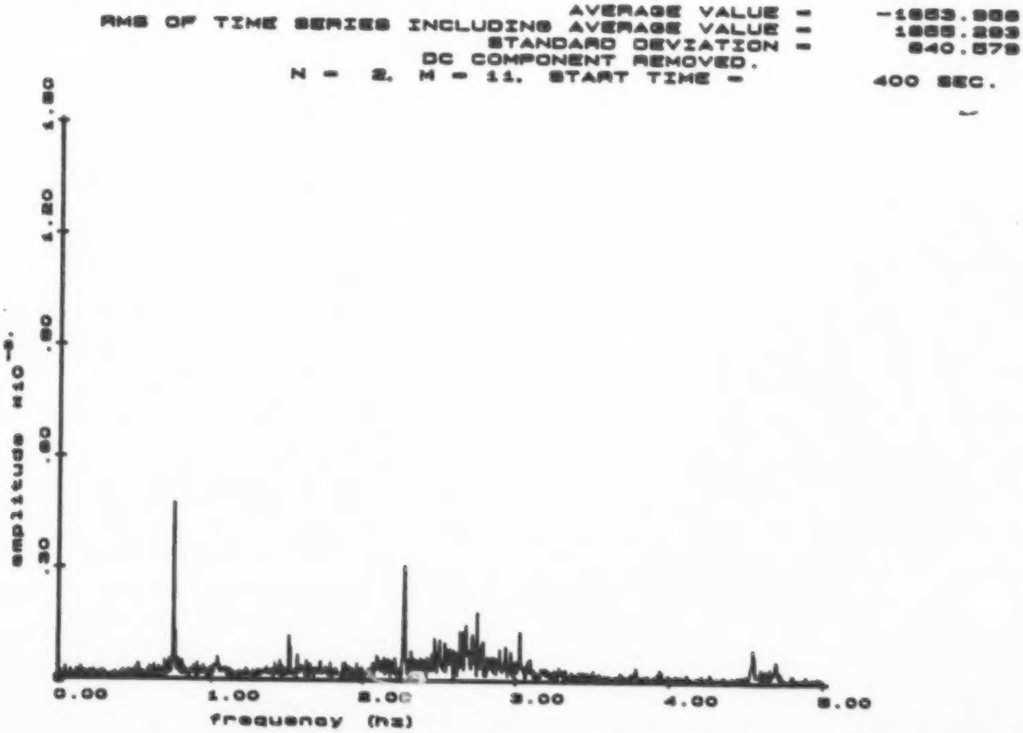


FIGURE 5: SPECTRAL ANALYSIS OF THE BLADE STRESS WAVEFORM AT THE A5 INNER NEUTRAL AXIS LOCATION

DESIGN FEATURES OF PROJECT EOLE PROTOTYPE 4 MW VERTICAL AXIS WIND TURBINE GENERATOR (VAWTG)

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SUMMARY

The salient features of the project definition which formed the basis of the design of the prototype 4 MW Darrieus VAWTG are first outlined.

The basic criteria for the selection of the site for the VAWTG are given and the selected site identified. The principal wind regime parameters are also given.

The VAWTG has five major subsystems which are the turbine rotor, the rotor support system and the mechanical, electrical and instrumentation systems. These are briefly described and the reasons for the selection of specific design options are given.

Performance data for three optional operating modes of the VAWTG are presented. The three modes are constant speed, variable speed and variable speed with power limit. Energy production estimates based on wind data as monitored at the selected site are also given.

The present status of the project is reviewed.

INTRODUCTION

A vertical axis, Darrieus wind turbine generator, designated Project EOLE, is under construction near Cap-Chat, Quebec. The project is jointly funded by Hydro-Quebec and the National Research Council of Canada (NRC) and management of the project is the responsibility of Hydro-Quebec. A Technical Review Board, comprising representatives of NRC and L'Institut de Recherche d'Hydro-Quebec, act as scientific advisors to the project management. Shawinigan Consultants Inc. are retained by Hydro-Quebec as engineering consultants, responsible for the overall design.

A Project Definition Technical Task Force was formed to produce a specification for known design parameters, to provide project guidelines and to identify areas where the study of options was necessary to establish design parameters. The Project Technical Definition document provided the basis for the initiation of the project and the design of the VAWTG.

This paper outlines the salient features of the Project Technical Definition and its translation into the final design which is described.

PROJECT OBJECTIVES

The major objectives of the project as set out by the Project Definition Technical Task Force are:

a) To confirm the technical feasibility of megawatt-scale VAWTGs.

b) To evaluate the design and to determine the operating, performance and control characteristics of megawatt-scale VAWTGs, and their interactions with the recipient electrical network.

c) To verify analytical techniques used for prediction of the technical performance and to indicate economic potential of VAWTGs.

d) To generate knowledge and experience of value to Canadian users and manufacturers of VAWTGs.

e) To encourage and enhance the development of Canadian industrial capability in VAWTGs and components.

f) To obtain operational experience with a megawatt-scale VAWTG.

g) To examine the environmental aspects of megawatt-scale VAWTGs.

PROJECT DEFINITION

The parameters specified by the Project Definition Task Force are as follows:

Swept area = 4000 m^2
Number of blades = 2 at 180 degrees
Height/diameter ratio = 1.5
Solidity = 0.15
Equatorial height/rotor height = Minimum
Blade airfoil section = NACA 0018
Rotor shape = Nominal troposkein
Struts = 2
Spoilers = None

Brakes:
Number of independent systems = 2
Main shaft brake = Low speed
Separate rotor parking lock = YES

Preliminary design wind regime:
Wind speed at 50m above ground = 6 to 12 m/s
Weibull factor = 2 (Rayleigh distribution)
Shear coefficient = 0.17

Design life = 30 years
Quality of power = Hydro-Quebec standards
Normal and emergency operating modes = Hydro-Quebec practice
Operation during network loss = Safe stop only
"Black-start" capability = Not required

Control Modes:
Fully-automatic (unattended) = YES
Manual over-ride with full protection = YES
De-icing/Anti-icing protection = NO - Detect and shutdown

Fig. 1 summarises the configuration as defined.

A number of parameters are not included in this list and were the subject of further study. Some of the options outstanding in the initial concept, such as guy cable and power train configurations, are indicated graphically in Fig. 2.

One of the most important decisions was the selection of the power rating. The basic shaft power equation for the wind turbine is:

$$P = 0.5pAC_pV^3$$

where: p = Air density
A = Swept area
C_p = Aerodynamic power conversion efficiency
V = Wind speed

The power coefficient C_p is a non-linear function of the tipspeed ratio X and:

$$X = wR/V$$

where: w = angular velocity
R = rotor equatorial radius

Substituting for $V = wR/X$ in the power equation gives:

$$P = 0.5pAC_p(wR)^3/X^3$$

The design point involves a particular C_p and corresponding X occurring at maximum power which may be either a true peak value or the limit value at the maximum operating wind speed depending on the shape of the C_p/X curve. It follows then that the shaft power rating P is proportional to w^3. In other words, the faster the VAWTG is allowed to rotate the more power it will produce. However there are technical and economic constraints to set a ceiling value.

The first constraint is that increased shaft power means increased structural loading and increased power train component ratings; both of which involve higher cost.

The second constraint is the effect on energy production. As the power rating is increased, the power versus wind speed characteristic is modified so as to increase the cut-in wind speed, at which power starts to be produced. The effect of this is to reduce the energy production at low wind speeds even though it is increased at high wind speeds. The probability density distribution of wind speed is such that low wind speeds are more frequent. The gain in energy production, therefore, progressively decreases, the operating time of the VAWTG decreases and the capacity factor decreases.

The electrical power output is the turbine output minus the power train losses and is therefore influenced by the type of power train. Furthermore, if the power train allows variable speed operation of the turbine, the turbine conversion efficiency can be optimised over the operating range of wind speed by appropriately scheduling the rotational speed to maximise energy production.

Assuming that all the power produced can be usefully absorbed by the grid, the ultimate criterion is the cost of the energy produced since this combines the effect of increased rotational speed and power rating on both energy production and the wind turbine and power train costs.

The selection of rated power and speed is therefore a complex issue which was resolved for the project by carrying out a study which examined all the factors which have been outlined for the specified turbine configuration. It was concluded that a power train comprising a synchronous generator and static frequency changer in conjunction with a turbine shaft nominal power rating of 4 MW at 14.25 rpm is the optimum configuration in terms of cost of energy and operational flexibility. The latter is an important consideration for a prototype unit.

A second study examined the feasibility of directly-coupling the generator to the turbine without an intermediate speed-increasing gearbox. A range of generator speeds was examined requiring single and multi-stage gearboxes and the directly-coupled option was selected on the basis of higher efficiency and reliability and reduced maintenance.

The design power train configuration is shown in Fig. 2 as the final concept.

Other studies were carried out to:

a) Compare available methods and computer codes for determining the aerodynamic performance and loading and for structural dynamic analysis.

b) Establish a design specification for the turbine in terms of the worst case loading conditions. These could be in operation, when parked during storm conditions or during erection of the turbine.

The project definition also gave a detailed list of design considerations for each of the subsystems: rotor, rotor support, power train and control and instrumentation.

Supplementary to the prime requirement of a favourable wind regime, the following factors were also given for consideration in site selection:

- Proximity to suitable transmission lines.
- Soil conditions.
- Convenience of access.
- Suitability for assembly and erection.
- Availability of land and services.
- Number of nearby inhabitants.
- Capability for erecting further units.

SITE SELECTION

The general area for the site for EOLE had earlier been established as the lower St. Lawrence valley and meteorological towers were installed on several of the most promising sites, on both north and south shores, as selected by Atmospheric Environment Services. The choice was eventually narrowed down to an area near Cap-Chat on the south shore having four possible locations. The final selection was based on best compliance with the supplementary site selection factors.

The wind regime as measured for the selected site has the following characteristics:

Annual average wind speed = 9.23 m/s at 60 m height
Weibull factor = 1.56
Shear coefficient = 0.11 at moderate wind speeds
(negative shear coefficients occurred at high wind speeds)

It will be noted that both the Weibull factor and shear coefficient are lower than the originally defined values. The reduced Weibull factor means that the most frequent winds are of lower velocity and the reduced shear coefficient means that the increase in wind speed with height above ground is also lower. Both effects, in this case, result in a reduction in energy production. However, the reduced shear coefficient also means reduced aerodynamic loading on the wind turbine structure. For design purposes therefore, the following conditions were applied.

For worst case storm conditions, the maximum wind speed is taken as 62 m/s with zero shear coefficient and for structural design purposes, the shear coefficient is taken as 0.17. The measured values are used for power and energy calculation.

The ambient temperature range is taken as -40 to 35 °C. For structural design purposes, -40 °C is taken as corresponding to maximum air density and hence maximum aerodynamic loading. Performance calculations are based on nominal air density at 15 °C.

DESIGN FEATURES

The Project Eole installation as designed is illustrated pictorially in Fig. 3.

Turbine Rotor

The detailed design of the rotor is based on extensive computation of the static and dynamic loading in all operating and non-operating conditions, including during installation, to ensure adequate margins on stresses and hence an acceptable fatigue life for the unit. The rotor is a complex structure having many natural frequencies and is subjected to a wide range of excitation frequencies from the harmonic components of the aerodynamic forces. The lowest 16 natural frequencies and the lowest 5 harmonic excitation frequencies are considered. The excitation frequency range is further extended by the requirement for variable speed operation. Dynamic analysis of rotor behaviour under all operating conditions required a major design effort which was resolved with a computer model which included the variable speed power train and enabled operating conditions to be simulated.

Fatigue analysis was carried out for the most highly stressed areas by computing the cumulative damage based on the stress amplitude and number of cycles related to the wind speed probability density distribution and the conditions and frequency of VAWTG startup and shutdown.

The primary components of the rotor are the central column, the blades and the horizontal struts. Basic structural details are provided in Fig. 4.

The central column is 96 m long and 5 m in diameter and consists of 6 sections of rolled and welded sheet steel having a thickness of 12 mm. The sections are joined by bolted spliced joints. Conical end sections, fabricated from 40 mm steel, reduce the diameter to a flange which is bolted to a matching flange on the shaft. These end sections also include provisions for attachment of the blades by bolted connections. Similar provisions are included at 20 percent and 80 percent of rotor height for bolted connection of the horizontal struts.

A damping device is mounted inside the column above the upper horizontal strut. It consists of a suspended 18 tonne weight having its horizontal movement relative to the column controlled by a spring and damper system. The damper system is optimally tuned to minimise loads and stresses caused by in-plane and out-of-plane forces acting to deflect the two-blade rotor from the vertical.

An access door is provided at the bottom of the column and a second door at the top of the column provides access to the upper bearing platform via an external ladder. A ladder system with staging platforms at 5.5 m intervals and a 500 kg capacity electrically-operated manlift are provided inside the column. There are equipment rooms at the top and bottom of the column.

The blades have a chord of 2.4 m and maximum thickness of 0.43 m and consist of a fabricated box-section in 6 mm steel with internal stiffeners and with fibreglass nose and tail sections. The fibreglass sections incorporate an aluminium mesh layer which is bonded to the box section to protect internal hydraulic piping and electrical cables and to minimise blade damage in the event of a lightning strike.

The blades are constructed in straight 5.7 m long sections and are connected together by either in-line or 4 degree offset bolted spliced joints. The troposkein shape is approximated as a straight length from each end of the central column connected by an arc of a circle in the equatorial region. The 8 degree angled connections are to achieve the arc. The blades are connected to the column by diagonal struts.

Although not specified in the project definition, aerodynamic brakes have been included for additional security against runaway. These are located in the tail section of the three blade sections closest to the equator and replace the fibreglass section used elsewhere. The brakes are hydraulically-operated from a redundant pump/accumulator system located in the central column and connected by high pressure lines running inside the blades. The two normal airfoil surfaces of the brake are effectively hinged at the tail tip and so are assisted in the opening direction by the aerodynamic drag. The actuators apply pressure to open and close.

Blade section details are given in Fig. 5.

The horizontal struts are structural stiffening members to assist in supporting the blades. Fibreglass cowlings are provided for the outer third of their length to reduce the aerodynamic drag. A walkway is provided on the strut with an access door in the central column for inspection of the strut-blade connection which is the most highly stressed area on the rotor. The strut connections to both column and blades are rigid to allow the distribution of transmitted torque between blades and struts.

Rotor Support System

The rotor support system consists of the structure supporting the bottom rotor bearing and the guy-cable system attached to the upper bearing platform to keep the rotor vertical.

The bottom bearing support structure consists of six reinforced concrete legs which serve the additional function of providing the frame for the housing of the power train equipment. This structure must not only take the weight of the rotor but also the additional vertical loading imposed by the guy-cable system. This amounts to a normal total vertical loading of 6000 kN. For design purposes, the design takes into account a uniform 50 mm ice coating which produces a total vertical loading of 9000 kN as the maximum with the VAWTG stationary.

The top bearing support system consists of six, 76 mm diameter, bridge-strand guy cables spaced at 60 degrees. The number was fixed at six as the least cost minimum which would allow a cable to be removed and replaced without dismantling the rotor.

The nominal guy angle to the horizontal is 35 degrees which is the optimum in terms of horizontal rigidity.

The guy cables are attached at the top to the upper bearing platform and at ground level to anchors whose design is dependent on the particular soil conditions.

Intermediate masts, at a radial distance of 90 m, are provided to support the guy cables. Their function is to reduce the unsupported cable length and thereby increase the natural frequency above the excitation frequency levels expected in operation.

The integrity of the support system design was confirmed by static and dynamic analysis.

To protect the VAWTG against lightning strikes and minimise damage, lightning rods are fitted to the upper bearing platform to protect the local instrumentation and electrical services.

The most probable ground path is through the guy cables and these are directly bonded at the top to the upper bearing platform and at the bottom to the VAWTG ground mat to bypass the cable end-connections.

The alternative path to ground is through the rotor. Slipring assemblies provide a low impedance bypass for the upper bearing and the lower bearing and pivot; the lower assembly being directly connected to the ground mat. As a further precaution, a grounding brush is provided on the generator shaft to bypass the generator.

The overall VAWTG ground mat interconnects the guy cables at the anchor points, the guy cable anti-resonance masts, the perimeter fence and the rotor support structure reinforcing steel in addition to providing the ground for the main electrical equipment.

Mechanical System

The mechanical system design is influenced by the results of extensive torsional analysis carried out for the complete rotating system of the VAWTG. This analysis, which included a mechanical equivalent of the generator and SFC, was carried out to determine whether the harmonic components of the aerodynamic torque, the harmonic components of the electrical torque, due to SFC operation, or the harmonic components resulting from a line-line short-circuit at the generator terminals would be capable of exciting any of the system natural frequencies. The results of this analysis indicated the advisability of including a flexible coupling.

The mechanical drive system arrangement is shown in Fig. 6.

The mechanical system includes the rotor top and bottom bearings, the rotor pivot, the mechanical brake and the flexible coupling.

The bottom bearing comprises spherical roller thrust and guide bearings supporting an alloy steel integrally flanged shaft within a cast steel housing. The assembly is oil-lubricated by an automatic dual pumping system. Triple seals and a collection system minimise the possibility of leakage on to the brake and generator.

The top bearing is similar in construction, but smaller since there is no torque transmission requirement, and is grease lubricated.

The rotor pivot is interposed between the bottom bearing and the rotor and allows for displacement of the rotor from the vertical. It consists of an elastomer thrust pad and a flexible link coupling for transmitting the torque. No lubrication is required and there is no backlash in the coupling. A vertical displacement of 3 degrees in any direction is allowable compared with less than one degree expected.

Maintenance provisions include hydraulic jacking systems to allow the upper bearing and the pivot/lower bearing to be removed without the need to dismantle the rotor.

The mechanical brake consists of two 5 m diameter, 65 mm thick discs each fitted with three equally-spaced calipers mounted on brackets which are bolted to the underside of the concrete building. The total nominal braking torque is 5400 kN i.e. about twice rated torque. The brake is normally used to stop from about 20 percent of rated speed in which case only one disc is used. However, in an emergency, the brake is capable of full stopping duty from overspeed.

A preliminary design applied all six calipers to a single disc. However, analysis indicated that with an extra disc the specified stopping duty from 20 percent of rated speed could be extended to a full emergency stop without excessive disc temperatures.

The brake is pneumatically operated to release and spring applied. With the VAWTG parked, all calipers are applied. This arrangement supersedes the parking lock specified in the project definition.

The flexible coupling is of the resilient type and consists of two ductile iron halves with cast lugs to accept the 16 pre-loaded elastomeric cylindrical elements which transmit the torque between the two coupling halves. Independent friction damping is included between the outer surfaces of the lugs and the outer cover to help control large amplitude, low frequency oscillations. No lubrication is required and the elements can be examined or replaced with the coupling in place.

The coupling caters for axial and parallel misalignment in addition to torsional flexibility and damping. An extension shaft connects the flexible coupling to the generator shaft.

Electrical System

The basic electrical system is shown schematically in Fig. 7. The grid interface is a conventional outdoor substation. All other electrical equipment is housed in the rotor support building except the emergency braking resistors which are outdoors adjacent to the building.

The electrical system consists of a 4.14 MVA, 3.7 MW, 3.6 kV, 19.24 Hz, 162 pole synchronous generator which is directly-driven by the turbine and connected to the Hydro-Quebec grid through a static frequency changer (SFC) and 6.5 MVA, 4.16/69 kV step-up transformer. The SFC converts the generator output to d.c. and then inverts it to a.c. at grid frequency. This asynchronous tie between generator and grid allows the turbine to be operated over a speed range to maximise energy production. The generator static excitation system is fed from the grid, through the 750 kVA auxiliary services transformer, and is controlled so that the generated voltage is proportional to rotational speed. The generator thereby operates at constant flux and the d.c. current in the SFC is approximately proportional to the electrical torque.

The SFC can transfer power in both directions so that the generator can be driven as a motor to start the turbine which is not reliably self-starting.

The generator-side converter is operated at full inversion for motoring and full rectification for generating. The grid-side converter is used to control the power transfer and hence the rotational speed. If the power tranferred exceeds the turbine output the deficit is taken from the rotational energy of the turbine rotor causing it to decelerate. If the turbine is developing more power than the SFC transfers then it will accelerate.

Filters are included in the speed control loop to make it insensitive to the two per revolution oscillations in torque produced by the two-bladed turbine rotor.The resulting torque and hence output power oscillation amplitude for EOLE will be less than one percent compared with up to 30 percent or higher for similar VAWTGs with conventional power trains.

Fifth and seventh harmonic filters are provided on the grid side of the SFC to absorb the harmonic currents generated by the SFC. Power factor correction capacitors are also provided to correct the grid side power factor to unity at half load. The power factor at full load will be about 0.9 leading.

In the event of a grid outage, braking load is provided by a resistor bank and generator excitation is provided by a battery. For other faults which prevent power transfer to the grid, the braking resistor is used in conjunction with the normal excitation system, if available. In normal operation, the SFC is used to electrodynamically brake the turbine.

The auxiliary services transformer supplies the building heating and ventilation system, building and exterior lighting and power supplies to the turbine rotor via sliprings at the lower end of the generator shaft and a 600 V cable running inside the shaft and drive train components to the lower equipment room in the rotor column. It also provides services to the remote control room and administration building. These services are additional to the main electrical system services which include a 10 kVA uninterruptible power supply (UPS) to ensure essential supplies in the event of loss of the grid and allow a safe shutdown of the VAWTG.

Control of the SFC determines the operation of the VAWTG and is carried out at two levels. The first direct level is by a micro-processor based system incorporated in the SFC which controls both thyristor converters. Closed-loop control consists of an inner loop, which sets the d.c. current level in accordance with a reference value, and an outer loop which provides the current reference signal and controls the VAWTG rotational speed.

The inner loop has fast response and includes safety features for protecting the SFC and generator.

The outer loop is relatively slow-acting since its dominant time constant is the accelerating time constant of the VAWTG rotating system, whose main components are the rotor and generator. If the rotating system is considered as a single rigid mass, this time constant is 32 s; 31 s of which is attributable to the rotor. The outer loop includes the torque ripple filters.

The outer loop speed reference signal and VAWTG operating mode commands are supplied to the SFC by the second level of control which comprises redundant programmable controllers (PCs) with on-line bumpless transfer.

All essential inputs are monitored at this level and these can be summarised as:

a) Wind speed
  - The mean value determines satisfactory conditions for VAWTG startup.
  - The instantaneous and mean values determine high-wind cut-out when the VAWTG is stopped to prevent both electrical and structural overload.
  - The mean value is used to compute the speed control reference level during variable speed operation.

b) Rotational speed
  - This provides the reset signal for the speed control loop.
  - To detect overspeed conditions and initiate the appropriate VAWTG shutdown mode.

c) Equipment monitoring
All components critical to safe operation of the VAWTG are monitored and, if conditions deviate from the acceptable range, the VAWTG is shut down. Some of the most critical are:

  - Rotor bearing temperature and vibration.
  - Generator temperature and vibration.
  - Rotor stresses.
  - Guy cable tension.

Signals not provided directly by the main electrical equipment are supplied by the data acquisition system described under instrumentation.

The PC is equipped to carry out all control functions necessary to operate the VAWTG. In addition to full control of the electrical equipment, it also controls the aerodynamic and mechanical braking systems.

The equipment layout in the building is shown in Fig. 8. In ultimate unattended operation, the local control room, item 8 in Fig. 8, will be used primarily for maintenance purposes. However, for the startup and evaluation stage of the project, a remote control room is provided.

The VAWTG/operator interface in the control room consists of two colour video display units (VDUs), one of which is for alarm display only, and a keyboard to allow the operator to access any part of the system for information, select automatic or manual over-ride operation and any one of three VAWTG control modes. A second keyboard allows changes to be made to level settings or control sequences. The interface communicates with the PC and vice versa via an information management unit (IMU).

An independent microcomputer is provided for off-line program development and de-bugging before downloading to the PC.

A printer and 3-pen recorder are provided to produce hardcopy.

Instrumentation

The instrumentation system can be segregated into rotor-based and ground-based subsystems.

Rotor-based instrumentation sensors include:

- Strain gauges, accelerometers and ice detectors on each blade.
- Wind speed and direction, ambient temperature and bearing temperature on the upper bearing platform.
- Aerodynamic brake open and closed status and drive train torque.

The instrumentation system also transmits the signal to deploy and close the aerodynamic brakes.

A 2 kVA UPS in the rotor lower equipment room ensures that essential supplies are available for orderly shutdown under emergency conditions.

Communication between the data acquisition equipment in the control room and the lower equipment room in the rotor column is over a fibre-optic link which includes a rotary joint (optical slipring). The rotary joint is incorporated with the conventional power supply sliprings into an assembly mounted on the lower end of the generator shaft. Two additional sliprings are included in this assembly for a hardwired circuit which allows the operator to directly deploy the aerodynamic brakes.

The optical link employs wavelength multiplexing/de-multiplexing with multi-channel data transmission. The overall data transmission system is based on pulse code modulation (PCM). This is converted to binary for the central processor by a decommutator in the control room.

Ground-based instrumentation sensors are hardwired and include:

- An anemometer on a nearby meteorological tower to provide a backup wind speed signal.
- Strain gauges for guy cable tension measurement.
- Rotational speed. Two sensors: one above and one below the flexible coupling.
- Lower rotor bearing temperature and vibration.
- Mechanical brake disc surface temperature.

Over 120 data channels are sequentially scanned at rates up to 5,000 samples per second which provides an adequate number of samples per cycle for the highest signal frequencies of interest and for the possible addition of extra channels in the future.

Signal conditioning amplifiers provide energising supplies required by the transducers and adjustments are available for voltage, gain or other changes in the field.

Data essential to the operation of the VAWTG are routed to the PC and vice versa over an RS232C serial link. A second RS232C link is provided for telephone line communication with a remote Hydro-Quebec dispatch centre to transmit VAWTG status information and to provide the remote operator with control of the VAWTG during unattended operation.

An IEEE488 serial link provides an interface with another computer and will be used during the VAWTG evaluation period for on-site processing of data.

Long term data storage is provided in the form of a 9 track tape. A 31 Mbyte hard disc continuously stores up to 30 minutes of data and then overwrites it during the next 30 minutes to provide short term data storage.

A printer allows hardcopy to be made from tape or disc and a VDU and keyboard provide the interface between the operator and central processor.

PERFORMANCE

The three optional VAWTG control modes are:

Mode A

In this mode the VAWTG is operated at constant rotational speed. The speed control loop of the SFC is therefore provided with a preset speed reference. This may have any value less than rated speed with the proviso that the particular speed setting does not result in the excitation of any of the VAWTG natural frequencies. This mode is similar to that dictated by the conventional power train configuration but with the two major differences of speed selectability and suppression of torque ripple effects.

Mode B

In this mode the wind turbine is operated at the tip-speed ratio corresponding to the maximum value of C_p i.e. at maximum aerodynamic efficiency. This is achieved by keeping the ratio of the speed control reference to mean wind speed at the appropriate value. A limit has to be applied when the rotational speed reaches rated speed to prevent rated output from being exceeded at high wind speeds.

Mode C

This mode is essentially similar to Mode B except that the speed limit is imposed at about 115 percent of rated speed. Rated power is then reached at a lower wind speed. For higher wind speeds, the output power is limited to rated by reducing the rotational speed.This can be achieved either by suitably scheduling the speed reference or by the use of an active power limiter.

Initially, the speed reference will be scheduled for all control modes. However, the PC is sufficiently flexible to allow the inclusion of an active power limiter during the evaluation period.

The operating characteristics for the three modes are shown in Fig. 9. Mode A characteristics are similar to Mode B except that the cut-in wind speed is higher at 0.244 pu or 5.47 m/s compared with 0.2 pu or 4.5 m/s.

Several mathematical models, covering a range of representation complexity, have been developed to simulate normal, and some abnormal, VAWTG operating conditions, from input wind speed to output electrical power to the grid. All the models show good agreement in the behaviour of the main variables, turbine shaft torque, rotational speed and output power. Fig. 10 presents the output from the simplest of these models to illustrate the starting sequence from standstill to normal generation and electrodynamic braking during rated wind conditions of 22.4 m/s at equator height.

From standstill to about 5 percent of rated speed the generator-side converter of the SFC cannot be naturally-commutated due to insufficient back e.m.f. from the generator and has to be force-commutated by ramping the d.c. current to zero, using the grid-side converter, before selecting the next thyristor pair.

Acceleration during starting is preset by scheduling the speed reference as a series of ramps. The SFC d.c. current, which is equivalent to the electrical torque, is then automatically controlled by the speed regulator to the level necessary to meet the demanded acceleration. This is shown by the similarity between the speed reference and actual speed curves.

The initial reverse power flow signifies motoring operation. This decreases to zero and reverses for generating operation as the wind turbine begins to produce accelerating torque. At the time of reversal, the generator-side converter of the SFC is transferred from the inversion to the rectification mode.

The low oscillatory content in the output power, when normal generation is reached, is demonstrated.

Electrodynamic braking is essentially a reversal of the acceleration process in that the speed reference is ramped to zero at a preset rate. The output power is then automatically adjusted to the level required to produce the necessary deceleration.

The annual energy production, calculated from the selected site wind regime data and the power curves for the three control modes and based on 100 percent availability, is as follows:

Mode A - Constant speed	: 7.33 GWh
Mode B - Variable speed	: 7.38 GWh
Mode C - Variable speed with power limit	: 8.28 GWh

For the wind regime of the selected site, variable speed operation offers minimal energy gain. Mode C in contrast offers a significant potential gain.

PROJECT STATUS

The status of the project, as of the end of November, 1985, is that the civil works, comprising rotor support structure, guy and mast anchors, ground mat, boundary fence and access roads, are complete.

The main electrical equipment and mechanical drive train components, from the the lower rotor bearing to the generator, have been installed.

Erection of the rotor is scheduled for Spring, 1986 and commissioning of the VAWTG in the Fall of 1986.

CONCLUSIONS

From the work carried out so far on the design, fabrication and installation, it has been learned that:

- Even though some of the components and subsystems are in the forefront of technology, they are within the capability of Canadian expertise.

- The manufacture of large VAWTGs has excellent potential for the development and expansion of Canadian industry.

When Project EOLE is operational in 1986, it will provide:

- A demonstration of operational reliability and availability.

- Experience of environmental impact.

- An opportunity to evaluate the design and performance.

At the end of the evaluation period, it is anticipated that Project EOLE will:

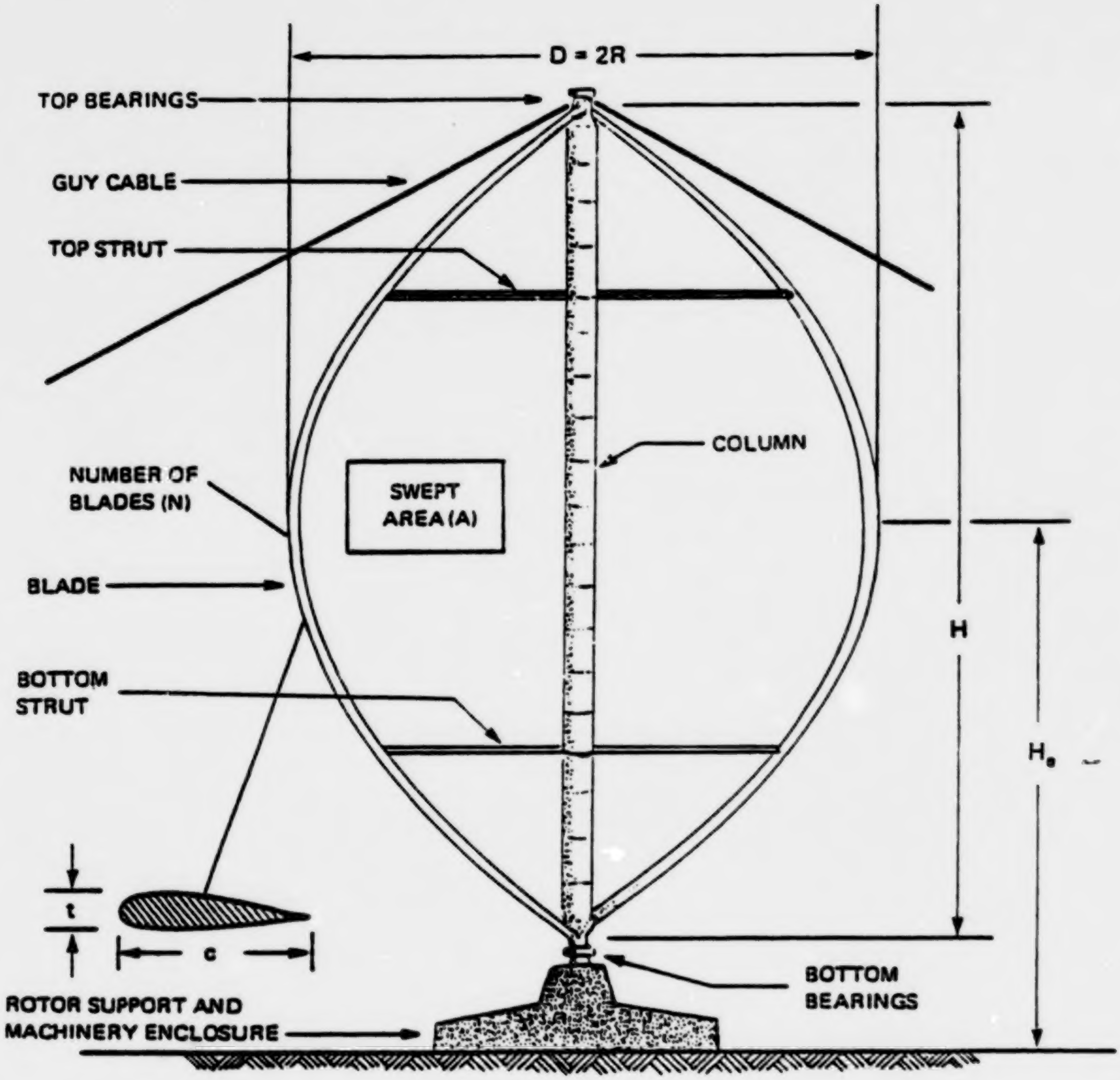
- Confirm the technical feasibility of large VAWTGs.

- Verify the analytical techniques used in the design.

- Encourage and enhance the prospects of building large VAWTGs in Canada for the domestic and international markets.

ACKNOWLEDGEMENT

The authors wish to thank the other members of the Project EOLE design team, specifically H. Benjannet, A.Galin, H. G. Ford, H. Bratcoveanu, G. H. Beausoleil and S. Chawla, for their help in ensuring the accuracy of the finer details presented in this paper.


D = 2R
TOP BEARINGS
GUY CABLE
TOP STRUT
COLUMN
NUMBER OF BLADES (N)
SWEPT AREA (A)
BLADE
BOTTOM STRUT
H
H_e
t
c
BOTTOM BEARINGS
ROTOR SUPPORT AND MACHINERY ENCLOSURE

$A = 4000\ m^2$
$H = 96\ m$
$D = 64\ m$
$N = 2$
$t = 0.43\ m$
$c = 2.4\ m$

Fig. 1 -- Project EOLE Parameters Specified in the Project Definition.

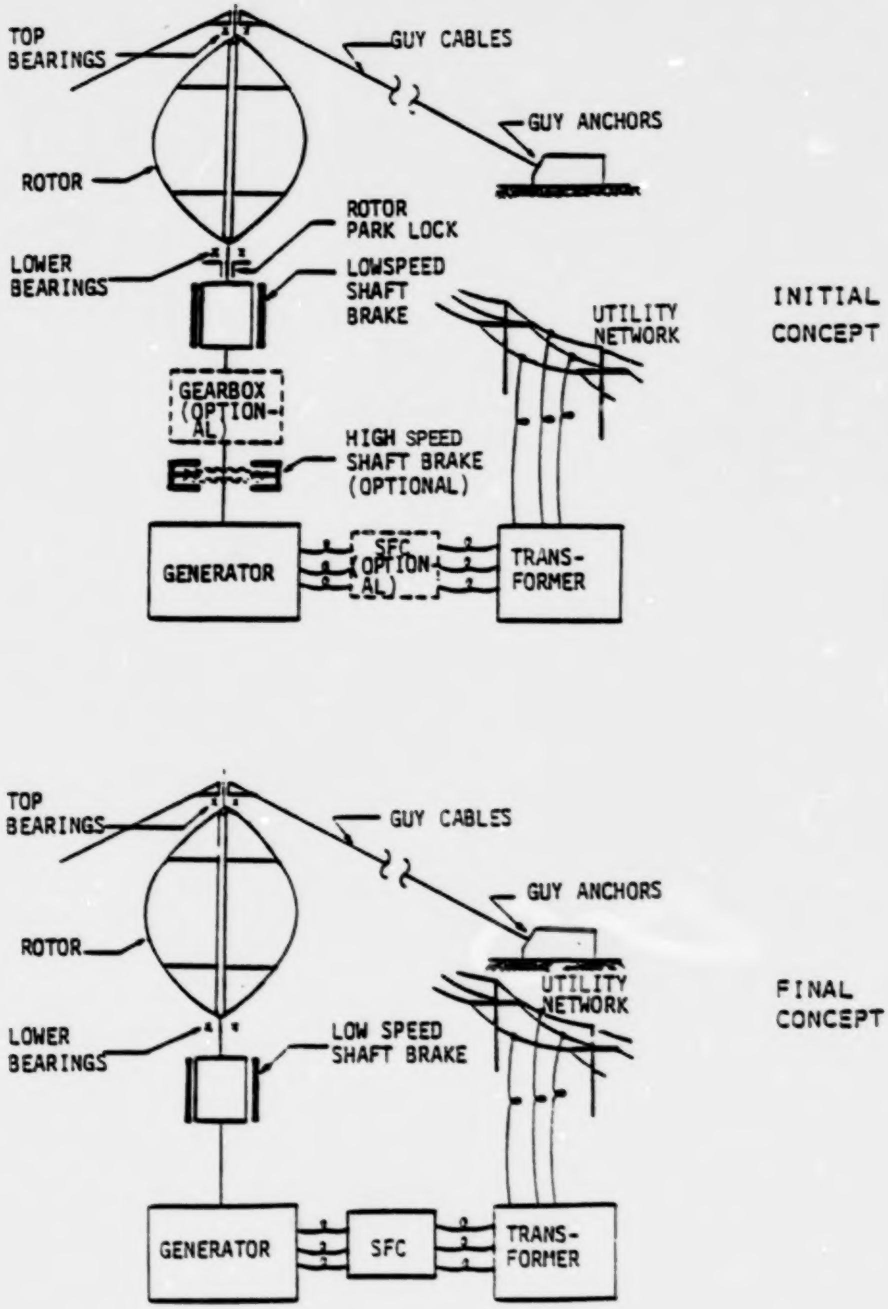

TOP BEARINGS
GUY CABLES
GUY ANCHORS
ROTOR
ROTOR PARK LOCK
LOWER BEARINGS
LOWSPEED SHAFT BRAKE
UTILITY NETWORK
INITIAL CONCEPT
GEARBOX (OPTIONAL)
HIGH SPEED SHAFT BRAKE (OPTIONAL)
GENERATOR
SFC (OPTIONAL)
TRANS-FORMER
TOP BEARINGS
GUY CABLES
GUY ANCHORS
ROTOR
UTILITY NETWORK
FINAL CONCEPT
LOWER BEARINGS
LOW SPEED SHAFT BRAKE
GENERATOR
SFC
TRANS-FORMER

Fig. 2 - Project EOLE Basic Concepts.

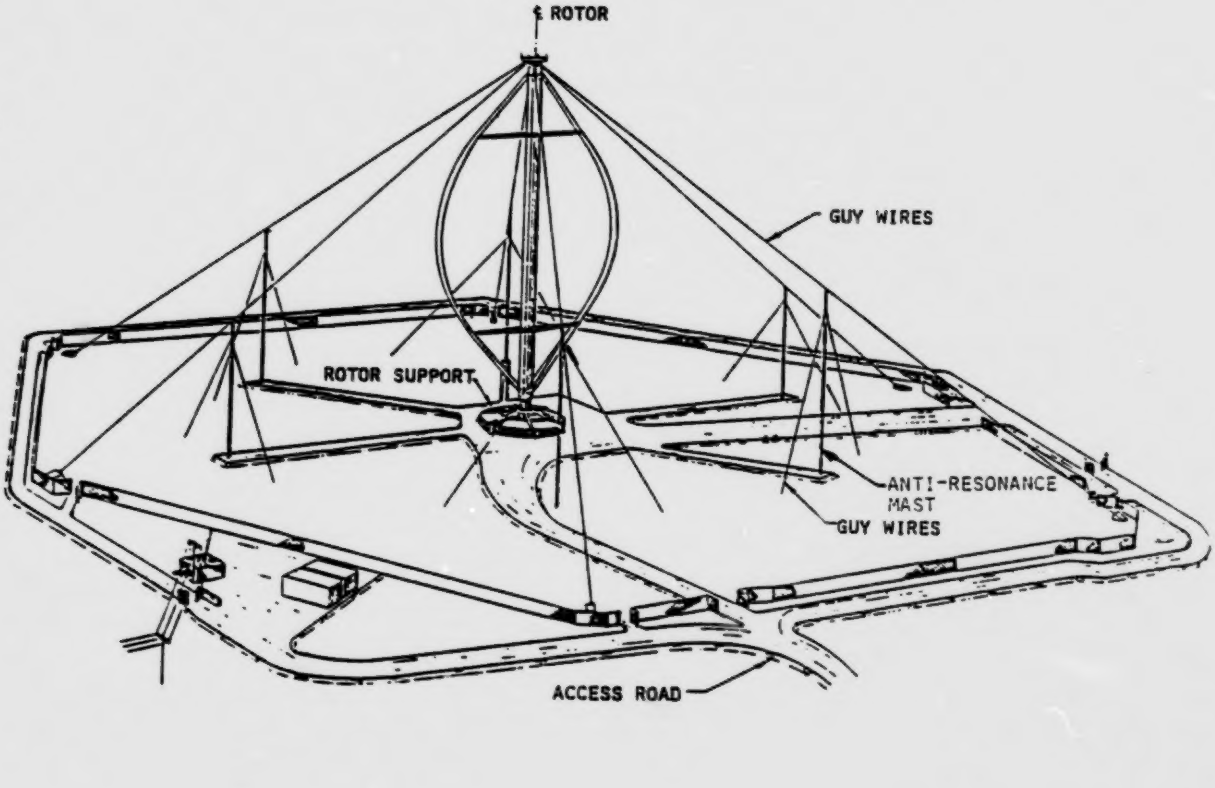

℄ ROTOR
GUY WIRES
ROTOR SUPPORT
ANTI-RESONANCE MAST
GUY WIRES
ACCESS ROAD

Fig. 3 - Project EOLE Design Configuration.

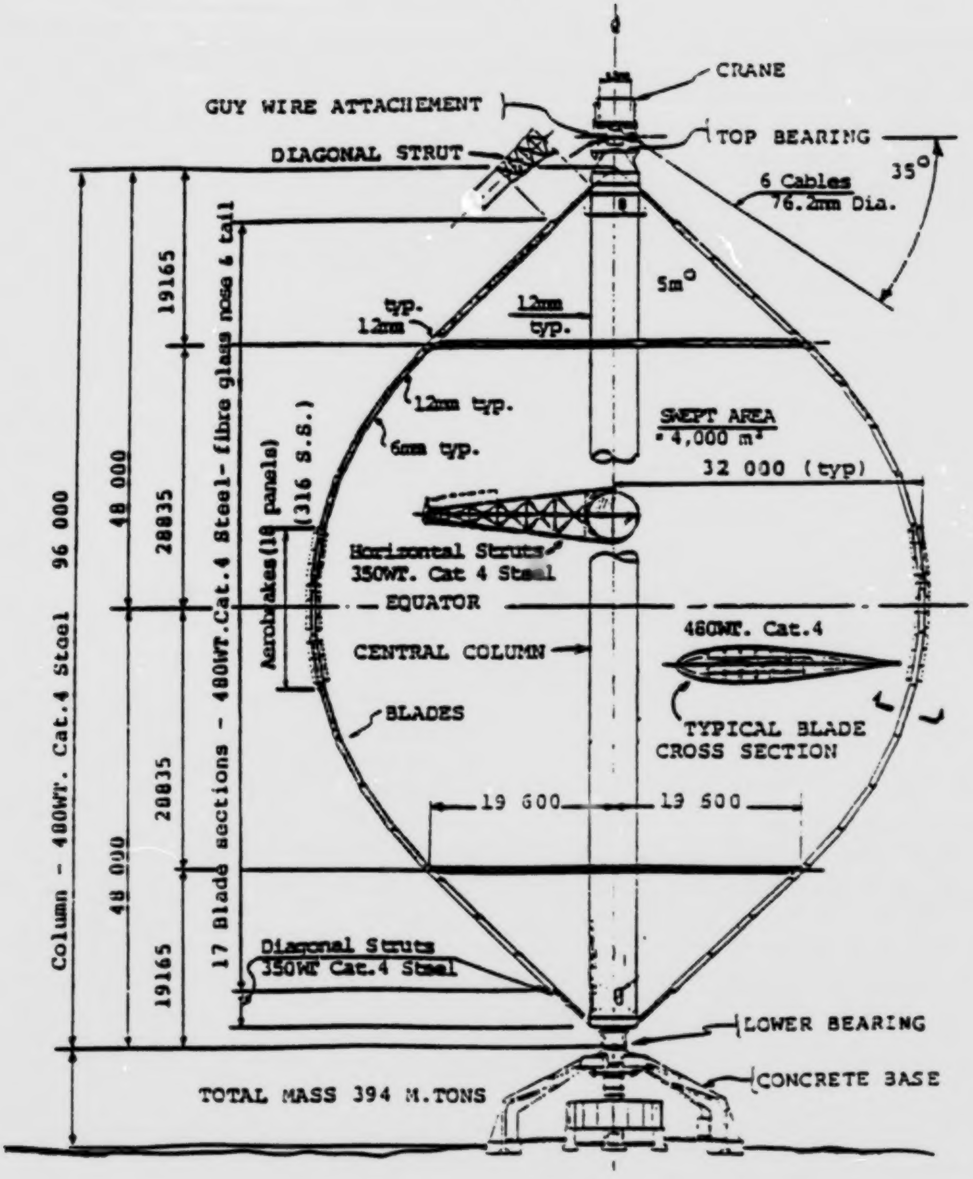
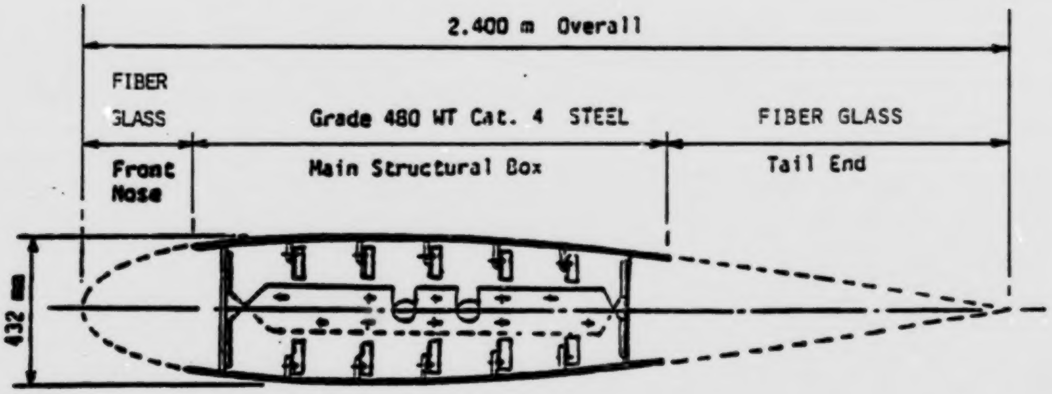
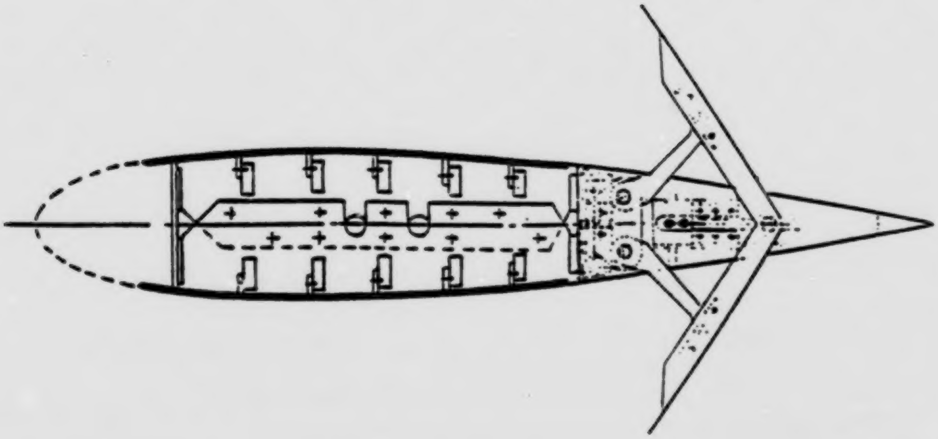

CRANE
GUY WIRE ATTACHEMENT
TOP BEARING
DIAGONAL STRUT
35°
6 Cables 76.2mm Dia.
5m°
typ. 12mm
12mm typ.
12mm typ.
6mm typ.
SWEPT AREA = 4,000 m²
32 000 (typ)
Horizontal Struts 350WT. Cat 4 Steel
EQUATOR
460WT. Cat.4
CENTRAL COLUMN
BLADES
TYPICAL BLADE CROSS SECTION
19 600
19 600
Diagonal Struts 350WT Cat.4 Steel
LOWER BEARING
CONCRETE BASE
TOTAL MASS 394 M.TONS
Column - 480WT. Cat.4 Steel 96 000
48 000
48 000
19165
28835
28835
19165
17 Blade sections - 480WT.Cat.4 Steel- fibre glass nose & tail
Aerobrakes(18 panels) (316 S.S.)

Fig. 4 - Rotor Structural Details.


2.400 m Overall
FIBER GLASS
Grade 480 WT Cat. 4 STEEL
FIBER GLASS
Front Nose
Main Structural Box
Tail End
432 mm

a) - Normal Blade Section.



b) - Blade Section Including Aerodynamic Brake.

Fig. 5 - Rotor Blade Sections.

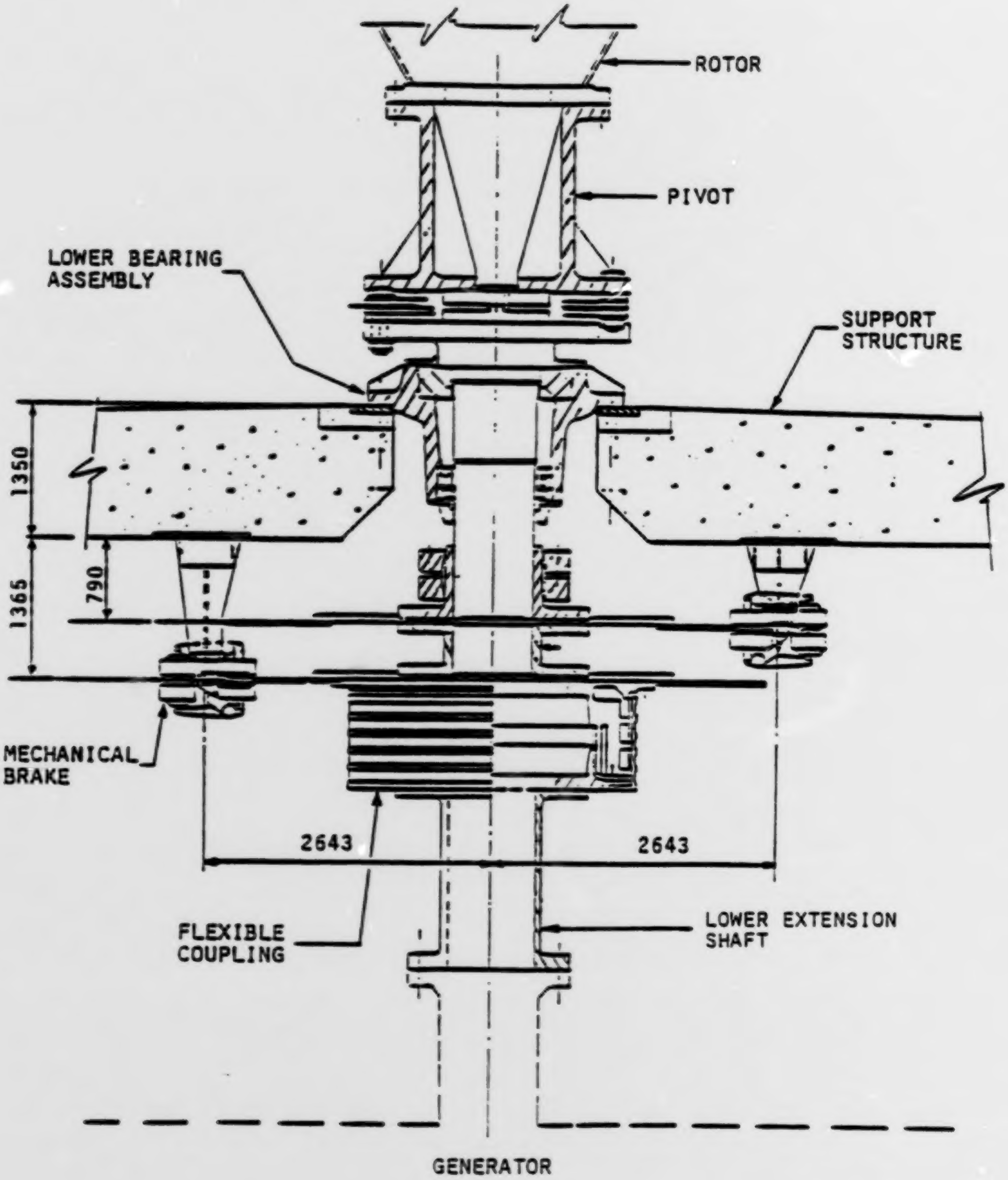

ROTOR
PIVOT
LOWER BEARING ASSEMBLY
SUPPORT STRUCTURE
1350
1365
790
MECHANICAL BRAKE
2643
2643
FLEXIBLE COUPLING
LOWER EXTENSION SHAFT
GENERATOR

Fig. 6 - Mechanical Drive Train Arrangement.

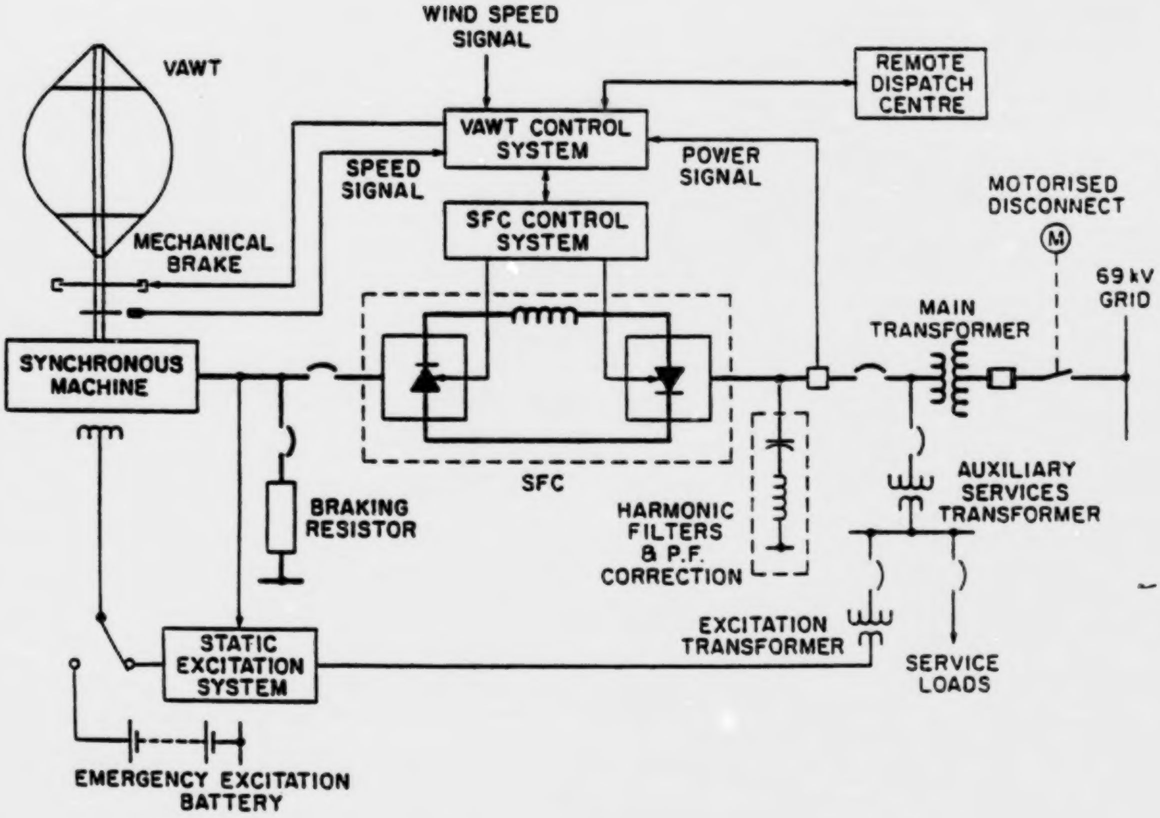

WIND SPEED SIGNAL
VAWT
REMOTE DISPATCH CENTRE
VAWT CONTROL SYSTEM
SPEED SIGNAL
POWER SIGNAL
SFC CONTROL SYSTEM
MOTORISED DISCONNECT
M
MECHANICAL BRAKE
69 kV GRID
MAIN TRANSFORMER
SYNCHRONOUS MACHINE
SFC
AUXILIARY SERVICES TRANSFORMER
BRAKING RESISTOR
HARMONIC FILTERS & P.F. CORRECTION
EXCITATION TRANSFORMER
STATIC EXCITATION SYSTEM
SERVICE LOADS
EMERGENCY EXCITATION BATTERY

Fig. 7 - Basic Electrical Scheme.

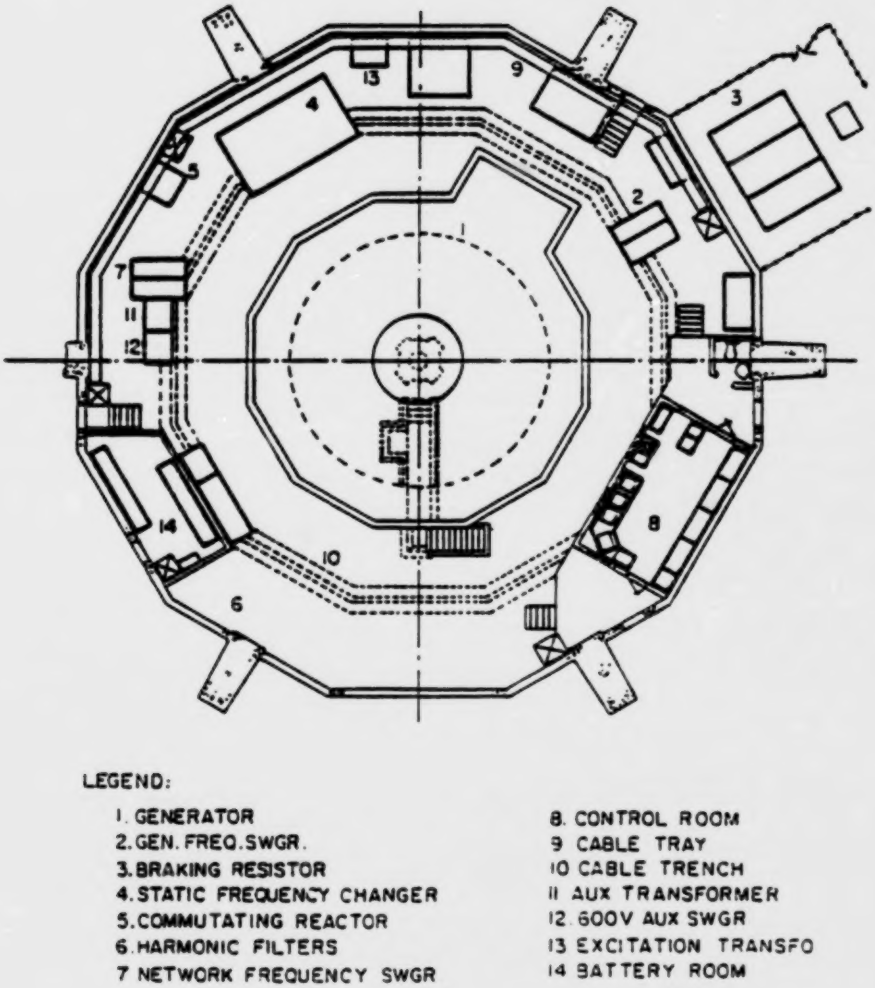
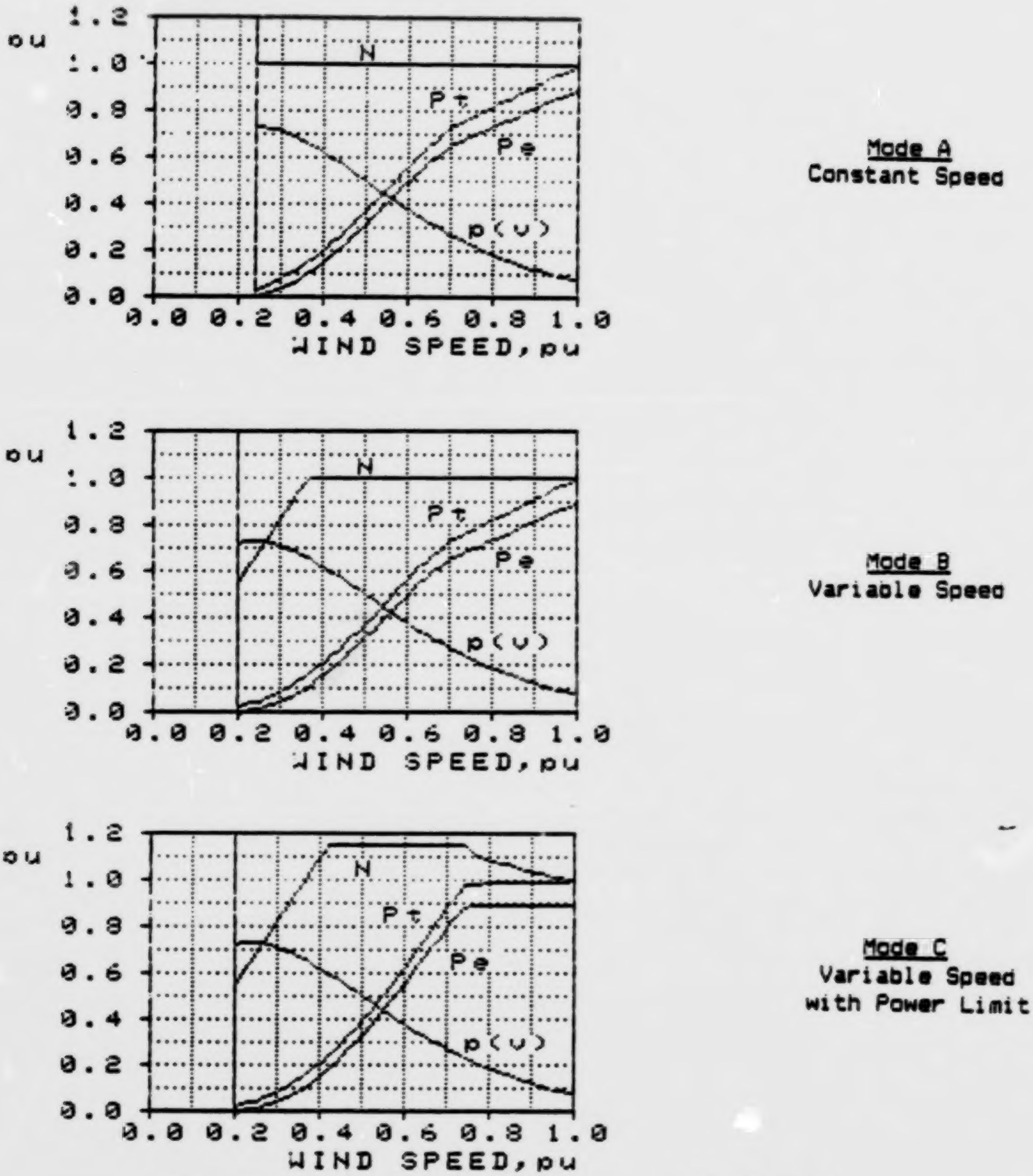

1
2
3
4
5
6
7
8
9
10
11
12
13
14
LEGEND:
1. GENERATOR
2. GEN. FREQ. SWGR.
3. BRAKING RESISTOR
4. STATIC FREQUENCY CHANGER
5. COMMUTATING REACTOR
6. HARMONIC FILTERS
7 NETWORK FREQUENCY SWGR
8. CONTROL ROOM
9 CABLE TRAY
10 CABLE TRENCH
11 AUX TRANSFORMER
12 600V AUX SWGR
13 EXCITATION TRANSFO
14 BATTERY ROOM

Fig. 8 - Rotor Support Building Electrical Equipment Layout.



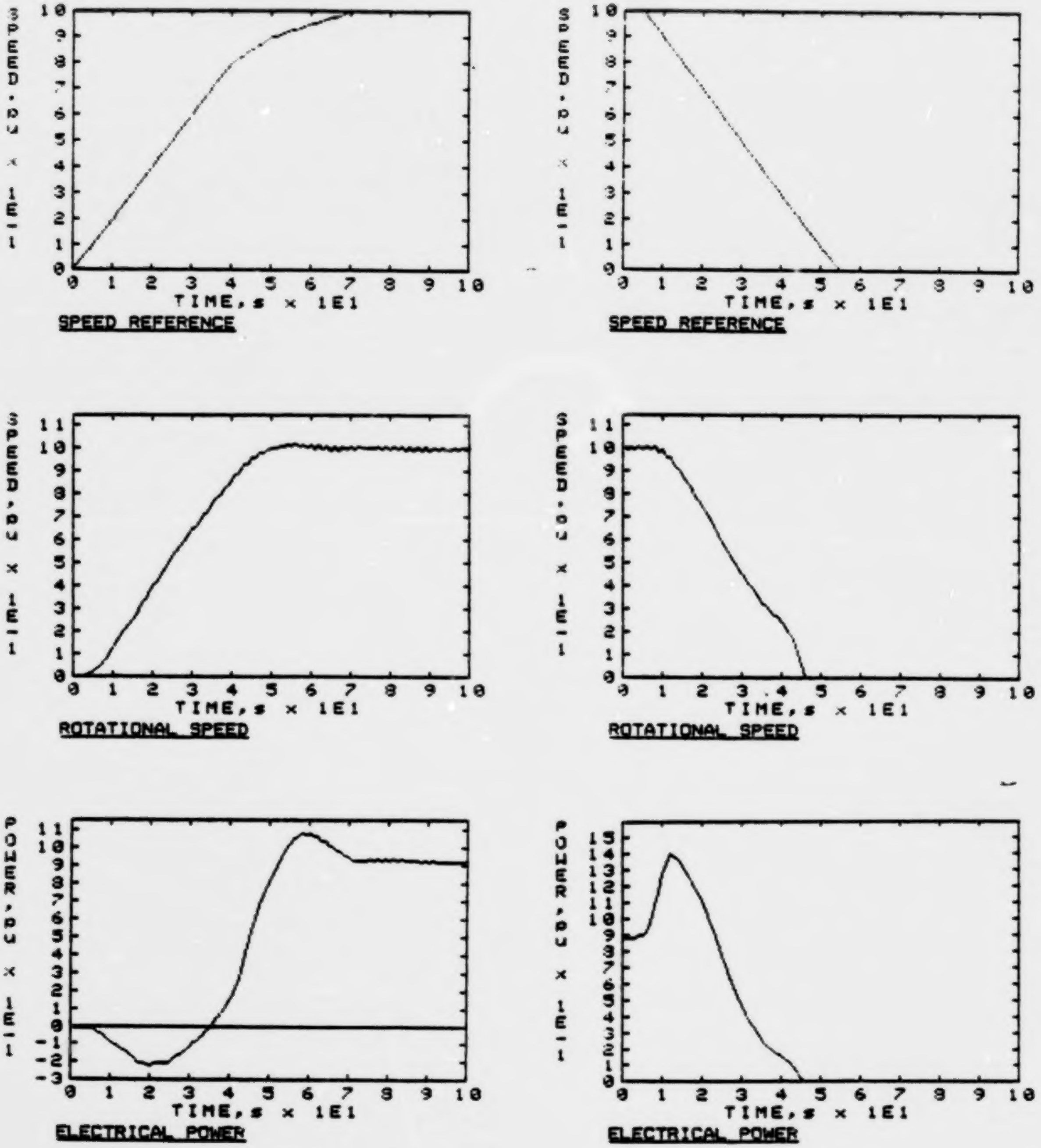
Mode A
Constant Speed

Mode B
Variable Speed

Mode C
Variable Speed
with Power Limit

KEY: N = Rotational speed (1 pu = 14.25 rpm)
Pt = Turbine shaft power (1 pu = 4 MW)
Pe = Electrical output power (1 pu = 4 MW)
p(v) = Wind speed probability density (x 0.1)
1 pu wind speed = 22.4 m/s at equator height

Fig. 9 - Performance Characteristics for the Optional Control Modes.



Starting

Electrodynamic Braking

Fig. 10 - Starting from Standstill and Electrodynamic Braking at Rated Wind Speed.

(For pu base values see Fig. 9)

FATIGUE LIFE ASSESSMENT OF VAWT COMPONENTS

by D.J. Malcolm
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L5C 2V8

Presented at Canadian Wind Energy Conference
December 9 - 10th, 1985, Ottawa

ABSTRACT

Wind turbines, and especially vertical axis wind turbines, have been justifiably described as giant fatigue testing machines. Some of the structural and mechanical failures due to fatigue in newer machines are only now becoming apparent as the required high number of cycles has been accumulated.

The loading environment of any component in a wind turbine is clearly not constant but varies with the mean wind speed and varies additionally in a random manner. The task of relating the measured data (in the form of rms stresses) to material fatigue S-N information and the expected wind regime has been investigated in recent years at Sandia National Laboratories. This paper reviews the basis for this procedure and describes the findings when applied to the blades of the Indal Technologies 6400 series vertical axis wind turbines.

The assumptions inherent in the fatigue life assessment have been tested against stress data which have been processed by the rainflow algorithm into effective stress excursions. The results of this comparison are also presented.

Introduction

The Darrieus rotor vertical axis wind turbine (VAWT) was patented in 1931 but has received the attention of engineers and developers for only the last 15 years. In that time it has been shown to be aerodynamically, structurally and economically competitive with the more traditional horizontal axis wind turbine (HAWT).

One major difference between the two classes of machines is that whereas the aerodynamic loading on HAWT blades is constant (in ideal conditions), the loading on VAWT blades is intrinsically cyclic. This leads to cyclic response in the structure so that all of the components in the rotor and drive train experience fatigue loading. Design for fatigue failure is as important as design for peak loading conditions.

The fatigue cycles in any one component may have contributions from three sources: stops and starts, random excitations while stationary, and normal operation. There is evidence that fatigue damage due to the first source is minor (but not insignificant) and there is insufficient documentation on the second type of behaviour. The majority of fatigue damage is considered to occur during normal operation to which this paper is therefore restricted.

The strength of materials under cyclic loading is a subject that is best described by empirical study and rules. The strength varies not only with the number and intensity of cycles but also with the order of their application, the surface finish, the mean stress and environmental conditions of temperature and corrosion. It is also very dependent on local stress concentrations and fretting loads. Detailed design is, therefore, extremely important. However, if laboratory tests on each detail cannot be carried out then much useful information can be obtained from the general literature available.

The number and intensity of fatigue cycles during the intended life of the rotor must be estimated. Even if the rotor has been instrumented and stress data are available for a range of wind speeds, the corresponding fatigue damage is not at once apparent. This problem has been addressed in a series of recent papers from Sandia National Laboratories (1,2).

The technique proposed at Sandia has been applied to several Darrieus rotors and the validity of some of the assumptions has been tested by comparison with field data. Some of these results as well as details of the technique are presented below.

Basis of the LIFE Program

Suppose that the standard deviation of stresses at the location of interest under a mean wind speed of V, is σ_v . Then if the process is narrow band and also Gaussian then it can be shown that the distribution of peak stresses, S, will follow a Rayleigh distribution. The probability density function is therefore

$$p(s) = \frac{s}{\sigma_v^2} \exp\left[\frac{-s^2}{2\sigma_v^2}\right]$$

Using this distribution it is possible to estimate the fraction of cycles at each stress level for the wind speed V. Furthermore, if the distribution of wind speeds for the relevant wind regime is known (for example it might be a Rayleigh distribution with a mean value of 8 m/s) then the total (annual) fraction of cycles at each stress level can be calculated if σ_v is known or estimated for the complete wind speed range.

It is still necessary to know the effective frequency of the cycles in order to calculate the total number of cycles at each stress level. For a truly narrow band process this frequency is self evident. For processes that are more broad band in frequency the mean zero crossing rate may be used. This rate can be obtained as the mean frequency of the spectral density of the stress.

The fatigue damage done by each stress cycle may be evaluated using Miner's rule which assumes that the fatigue damage, D, is independent of the order of application and is given by

$$D = \sum_{i=1}^{k} \frac{n_i}{N_i}$$

where n_i = the number of cycles experienced at level i, and N_i = the number of cycles required to cause failure at that level. When D = 1 then all of the fatigue life is exhausted and failure will occur.

The value of the number N_i may be obtained from test data in the form of S-N data which summarize the results of laboratory fatigue tests.

These essential steps form the basis of the LIFE code and are included in the flow chart on Figure 1.

Validation of LIFE Program

The assumptions within the LIFE program that may be questioned are the use of Miner's rule and the Rayleigh distribution of stress excursions. The first assumption has received considerable study in the general literature on fatigue. It is recognized that use of Miner's rule tends to overpredict the fatigue life of components subject to random loading. To be more accurate the laboratory fatigue tests should be done by using a random load generator rather than a constant amplitude.

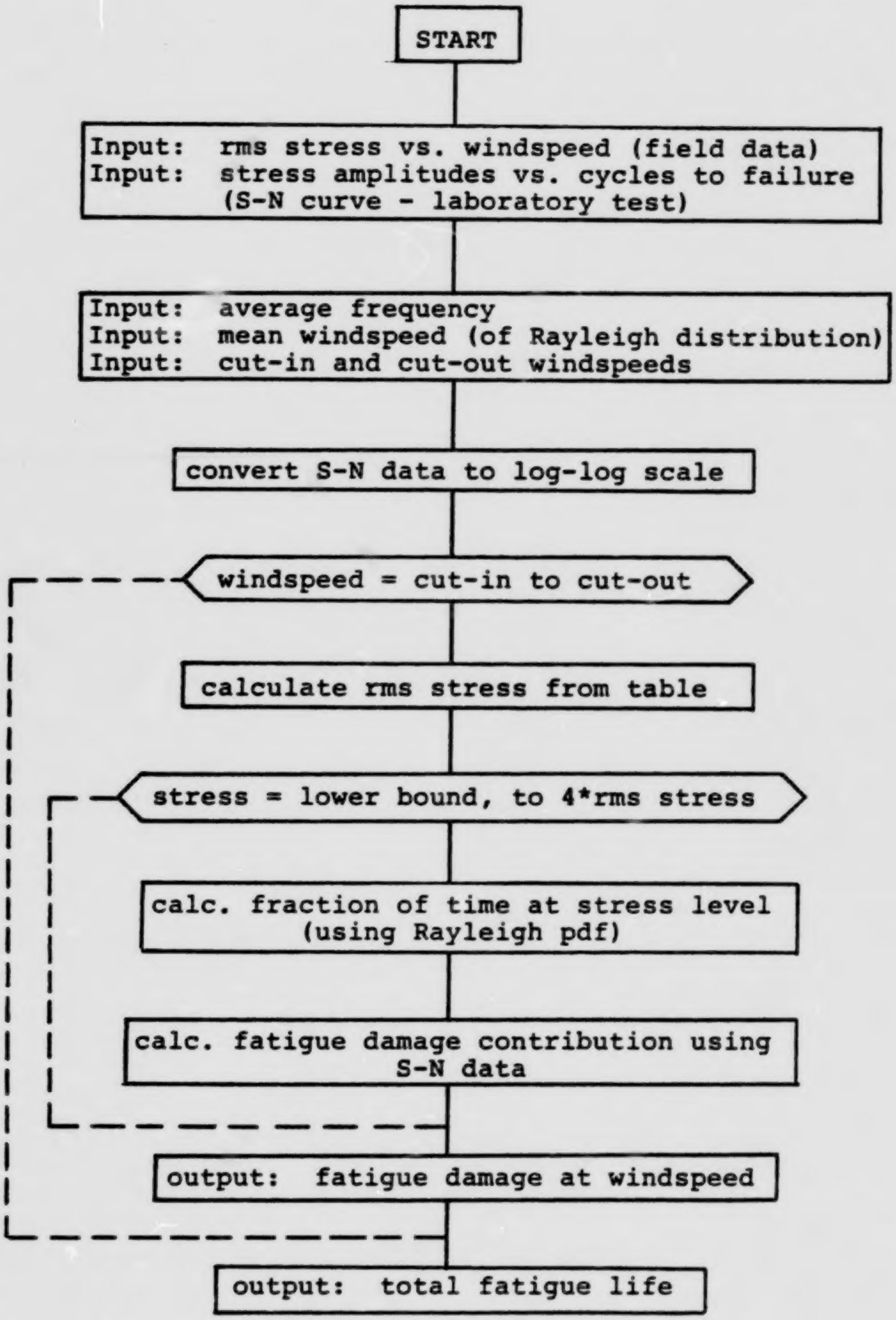
START
Input: rms stress vs. windspeed (field data)
Input: stress amplitudes vs. cycles to failure (S-N curve - laboratory test)
Input: average frequency
Input: mean windspeed (of Rayleigh distribution)
Input: cut-in and cut-out windspeeds
convert S-N data to log-log scale
windspeed = cut-in to cut-out
calculate rms stress from table
stress = lower bound, to 4*rms stress
calc. fraction of time at stress level (using Rayleigh pdf)
calc. fatigue damage contribution using S-N data
output: fatigue damage at windspeed
output: total fatigue life

Figure 1. Flowchart of LIFE Program

The second assumption of a Rayleigh probability density can be tested by decomposing typical time records of stress into the relevant stress excursions. This may be done through the use of a method such as the rainflow algorithm (3). This has been done recently by R.E. Akins (4) who examined a number of time records obtained from the Indal 6400 VAWT in California. The approach used by Akins was to compare the probability distribution obtained through a rainflow decomposition with the Rayleigh distribution based on varying fractions of the standard deviation.

The results obtained by Akins were dependent on the strain gauge location and on the wind speed. Sample comparisons are shown in Figure 2. In general it was found that use of 0.9 of the standard deviation gave good, if not slightly conservative, results.

Numerical Results

The critical locations on a Darrieus rotor are usually at the connections to the blade where some local stress concentrations are unavoidable. It is, therefore, important to establish the fatigue strength (S-N curves) of these details for use in the LIFE program.

The upper and lower root connections on the Indal 6400 were identified as possibly critical. A program was undertaken to make a number of specimens which duplicated the essential details of the bolted connection and to have these tested to failure under a number of stress levels. The results of these tests are included in Figure 3 as are the fatigue strengths reported for notched specimens and for bolted connections from other sources.

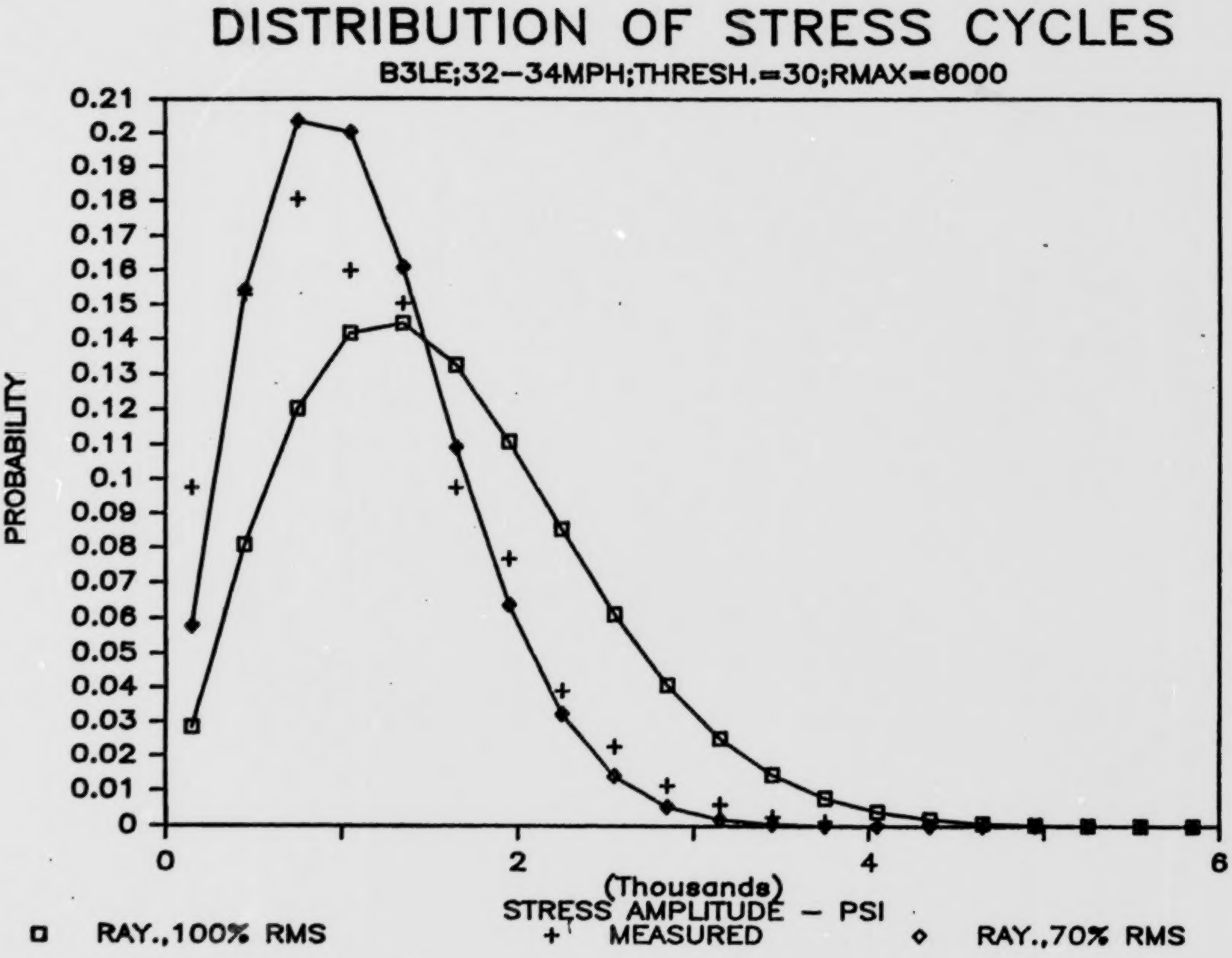

FIGURE 2. Comparison of Measured and Predicted Stress Distributions

LOG-LOG PLOT OF FATIGUE STRENGTH OF 6061-T6 ALUMINUM
R = min/max = 0,
DATA OBTAINED FROM ALCOA (Balfour Stulen 1974) [$K_t = 1.0$, $K_t = 4.0$]

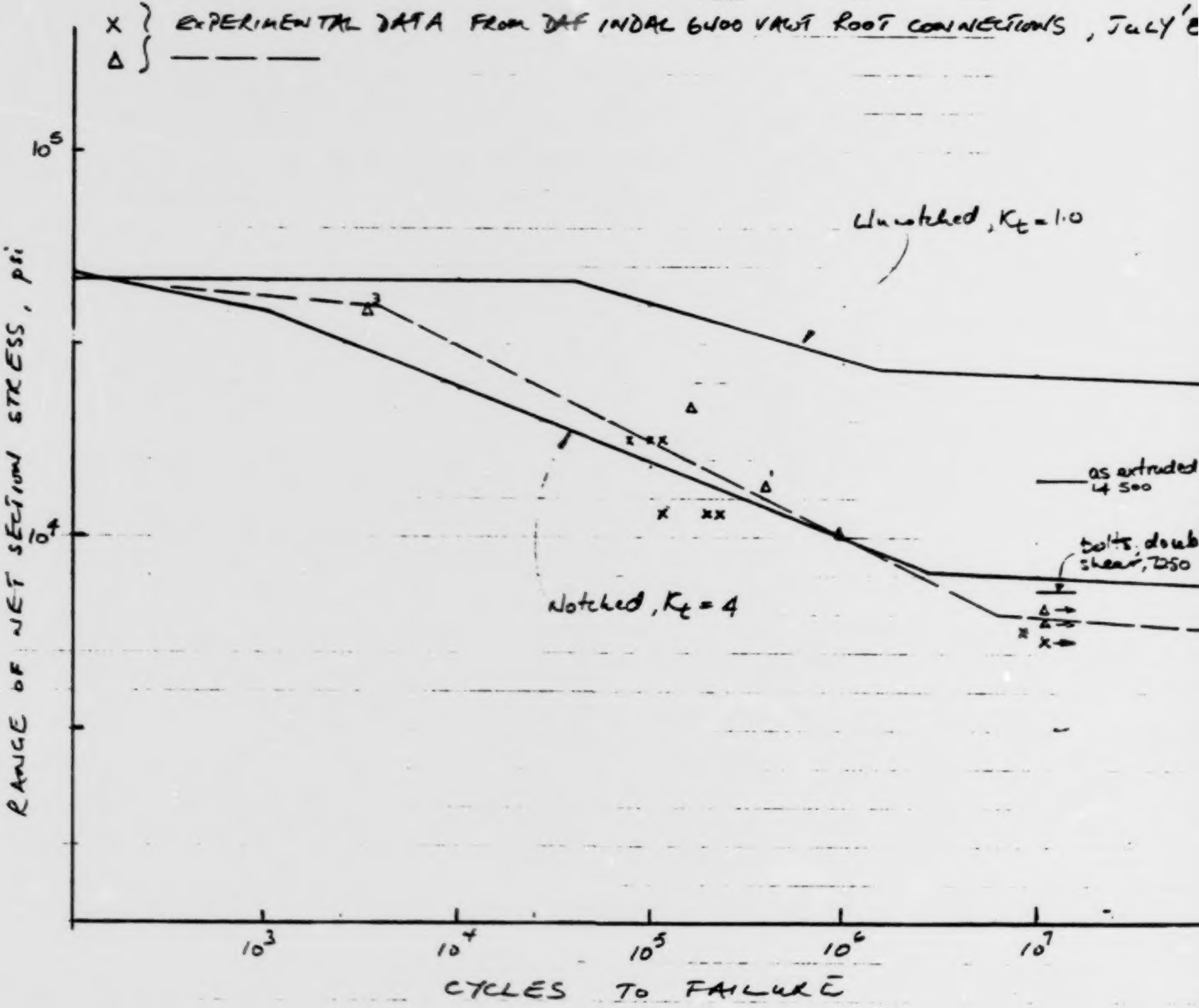

FIGURE 3. Summary of Fatigue Test Data.

The LIFE program showed that rather than the roots being critical it was the connection of the blades to the horizontal struts that was most critical. It was assumed that the bolt holes present at this location had the same fatigue strength as the root connections or slightly better. It was also assumed that around the leading of the two holes the stresses due to in-plane bending were not correlated to those due to out-of-plane bending. This assumption allowed the two rms stresses to be combined as the square root of the sum of squares. Using the measured relations between standard deviation of stress and windspeed such as that shown in Figure 4 it was predicted that the fatigue life at the Southern California Edison site would be 37.2 years.

It is of interest to note the changes in predicted fatigue life due to various changes in the data. For example, if the bending stresses are exactly correlated, then the fatigue life is reduced to 3.8 years. If, further, the full rms is used to describe the distribution of fatigue cycles then the fatigue life is reduced to 2.1 years, whereas using an rms modifier of 0.8 results in a life of 7.8 years.

The predicted life is also sensitive to the fatigue strength. If the S-N curve selected is that corresponding to reported tests of bolted connections in double shear (rather than single shear) then a life of 119.3 years is obtained. Use of the S-N curve for a notched specimen having a stress concentration of 4 increases the predicted fatigue life to 279.7 years.

Figure 5 includes some results obtained using a Rayleigh windspeed distribution with a mean of 16 mph (7.2 m/s) in place of the measured distribution at the SCE test site. This greatly increases the fatigue life although the mean windspeed has been increased slightly. This demonstrates the importance of using a distribution which accurately models the frequency of windspeeds near the cut-off speed.

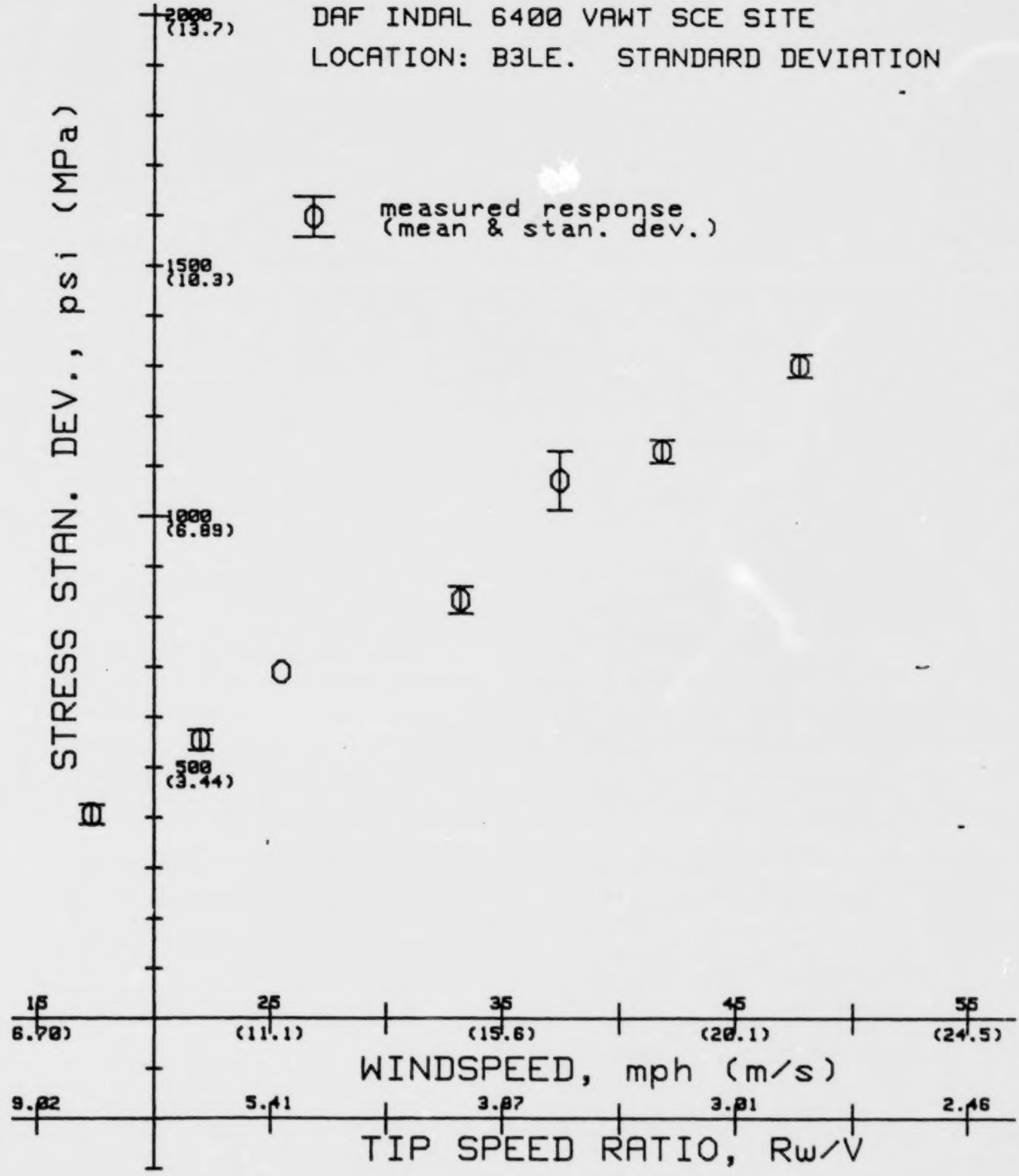

FIGURE 4. Stress Standard Deviation vs. Windspeed

Fatigue Life Prediction of VAWT Component

Location: 33 Leading Bolt Hole, Indal 6400

Wind Regime: SCE Devers Test Site, 50 mph (22.4 m/s) Cut-out

Fatigue Data	rms Modifier	Bending Correlation		Predicted Fatigue Life
		Full	Zero	
DAF root tests	1.0	X		2.1 years
DAF root tests	0.9	X		3.8
DAF root tests	0.8	X		7.8
DAF root tests	0.9		X	37.8
Kt = 4 notched	0.9		X	579.7
Bolted double shear	0.9		X	119.3
16 mph (7.2 m/s) mean Rayleigh wind regime (mid-rotor)				
DAF root tests	0.9		X	182.2
DAF root tests * .8	0.9		X	34.7
DAF root tests * 1.1	0.9		X	399.1

Figure 5. Summary of Fatigue Life Predictions
Indal 6400, SCE Site

Conclusions

The LIFE program has proved to be of considerable use in bringing together information on fatigue strength, measured stress data and the observed wind regime. However, the limitations of the program must always be borne in mind. These include:

- Use of Miner's rule has been known to overpredict fatigue lives under varying loads by up to four times.
- Fatigue damage due to stops, starts and while stationary has been neglected. It is recommended that at least 0.1 of the damage be considered to occur under these conditions.
- The fatigue damage is sensitive to any modification of the rms of field stresses. Modification by a factor of less than 1.0 should be included only if verified by examination of data by the rainflow (or other) algorithm.
- The fatigue damage is sensitive to the exact windspeed distribution, especially to the frequency of high winds. Assumed distributions, such as a Rayleigh distribution, may be adequate for predicting total energy output but should not be trusted for predicting fatigue damage.
- Fatigue damage is also sensitive to the fatigue strength and to any reduction in that strength due to environmental factors. Due to this and the above observations it is recommended that predicted fatigue lives of at least 500 years be required to assure the trouble-free operation of commercial wind turbines.

References

1. P.S. Veers, "Blade Fatigue Life Assessment with Application to VAWTs", ASME Journal of Solar Energy Engineering, Vol. 104, May 1982, pp. 106-111.

2. T.D. Ashwill & N. Slack, "Fatigue Life Prediction for Vertical Axis Wind Turbine Blades Using the Life Program", Sandia National Laboratories/New Mexico Engineering Research Institute

3. S.D. Downing and D.F. Socie, "Simple Rainflow Counting Algorithms", Int. Journal of Fatigue, Jan. 1982, pp. 31 - 40.

4. "Initial Analysis of Structural Data. DAF 6400 Rotor Revised Configuration", prepared for Southern California Edison Ltd. by R.E. Akins, Washington Lee University, Virginia, June 1985.

Projet Eole, December 1985

presented by
Jacquelin Déry
Administrateur d'ingénierie
Projet Eole
Hydro-Québec

1985 Canadian Wind Energy Symposium

Ottawa
December 9 - 10, 1985

1985 was a busy year for Projet Eole, both at the equipment suppliers' plants and at the site chosen for installation of the aerogenerator, Cap-Chat. The project is now approximately 80% complete with testing and evaluation of the installed components well under way.

Eole is a research and development project whose purpose is to evaluate a multimegawatt vertical-axis aerogenerator. It is a joint venture shared equally by the National Research Council Canada and Hydro-Québec's research institute, IREQ. The aim of these two sponsors, since the out set, has been to encourage the development of a Canadian multimegawatt-aerogenerator industry.

The project is the result of a concerted effort by a large number of organizations. In addition to the two sponsors, it involves the project manager, Hydro-Québec, the consulting engineers, Shawinigan/Lavalin, and the various manufacturers and suppliers of components.

The cost of the project was established at $35.2 million with the completion date set for 1986. Breakdown shows that permanent equipment and engineering account for most of this cost, with permanent equipment totaling $15 million.

Responsibility for the execution of Projet Eole is in the hands of the project manager, whose main task consists in making sure the work assigned to consulting engineers and manufacturers complies with the stated definition of the work and Hydro-Québec's standards and procedures. The project manager is also responsible for organizing and coordinating the on-site work, up to the time of transfer of the completed installation.

The base configuration of Eole is the result of technical choices made by NRCC and IREQ in close collaboration, between 1978 and 1980. A preliminary technical definition of the project was published in March 1981.

The general characteristics of the aerogenerator are given below and illustrated in the schematic in Fig. 1.

Rotor: troposkien shape
Drive train: at ground level
Height: 110 m
Guy wires: 6
Generator: low-frequency synchronous AC-type, direct drive, 13 m in diameter
Capacity: 4 MW at 14.25 rpm at winds of 20.7 m/s

The preliminary design was completed early in 1983 and Cap-Chat in the Gaspé Peninsula was selected as the installation site.

Civil engineering work at the site started in June 1984. Site preparation and construction were performed by local manpower, with Hydro-Québec's Construction Directorate acting as general contractor. Work went on smoothly and by the end of 1984 the concrete structure of building enclosure had reached completion.

Eole comprises four manufacturing "packages": the rotor, the electrical and control systems, the drive train, and miscellaneous instrumentation.

The contract for the rotor was awarded to Versatile Vickers Inc. of Montreal in April 1984 and fabrication began the following fall. The rotor column is made of steel plates, 12 mm thick and 5 m in diameter. It consist of 29 separate modules already assembled at the plant in six sections, which will eventually be bolted one to another at the erection stage. As for the blades, the prefabricated sections will be spliced together two by two before shipping but the remainder of the assembly work will be done on site.

The contract for the supply and installation of the electrical and control systems was awarded to Canadian General Electric in April 1984. The control system takes the form of a static frequency converter which converts the low-frequency (0 to 20 Hz) output of the wind generator to 60Hz power for the grid. Connection to the grid is made at a nearby 69-kV transmission line via a step-up transformer.

The supplier of the mechanical drive train is Hayes-Dana Inc. Four contracts were awarded covering the bearings, pivot, flexible coupling and mechanical brakes.

The mechanical and electrical equipment was delivered on time.

At the site itself, the generator foundations were completed in the first few months of 1985, which meant installation of the various components could begin in spring. CGE installed the electrical equipment in early April. The stator and the generator reached the site in four sections which were assembled on site. CGE's contract also covered the installation and commissioning of the control system and the drive train.

Last October 29 saw the first mechanical system go into service and as recently as December 2 the generator was run in motor-mode for the first time.

It was announced last September that the installation of the rotor had to be postponed until 1986 owing to difficulties at the manufacturer's plant.

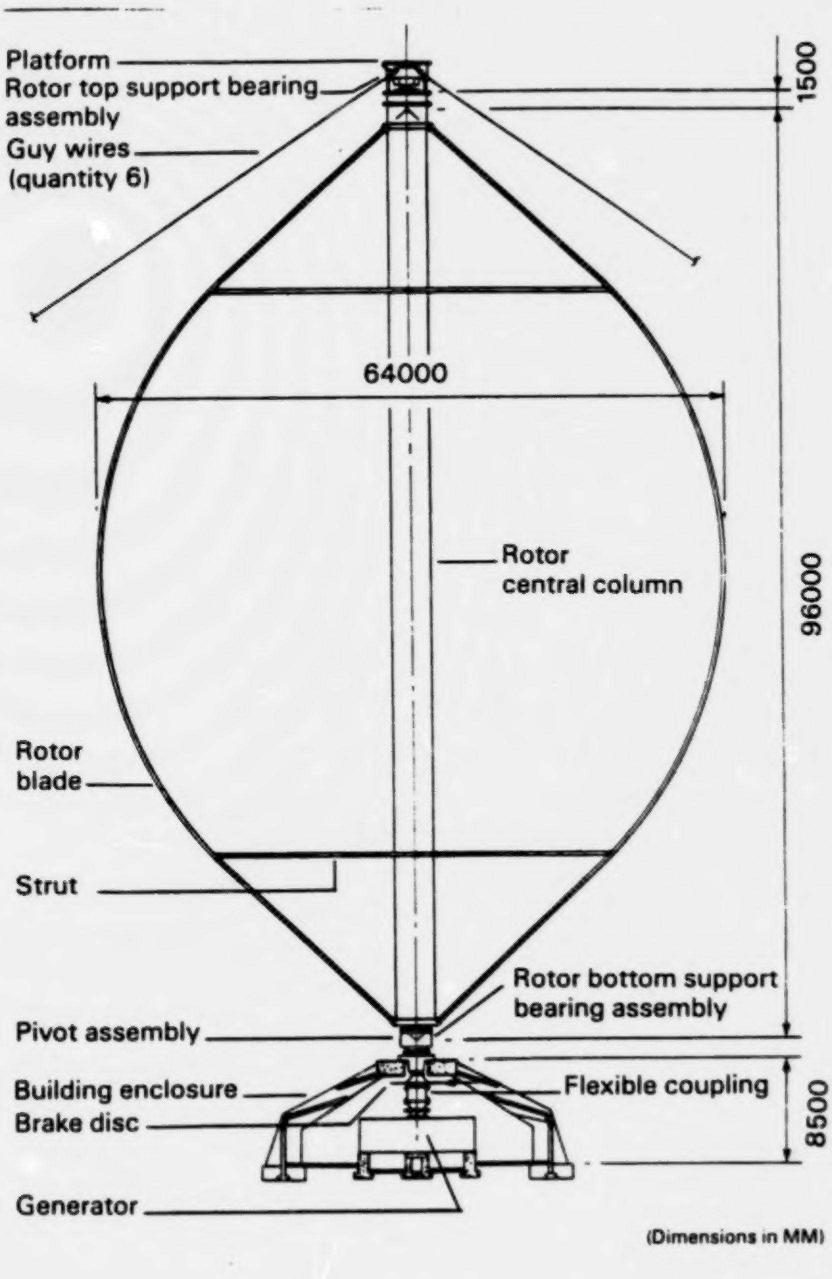
Platform
Rotor top support bearing assembly
Guy wires (quantity 6)
64000
Rotor central column
Rotor blade
Strut
Rotor bottom support bearing assembly
Pivot assembly
Building enclosure
Flexible coupling
Brake disc
Generator
1500
96000
8500
(Dimensions in MM)

Fig. 1: General Arrangement of Eole

CanWEA CONFERENCE TALK, OTTAWA, DECEMBER 10,1985

PROBLEMS TO OVERCOME IN NORTHERN AND REMOTE WIND ENERGY APPLICATIONS.

Jason Edworthy[1]

Abstract

The most promising markets in Canada for wind energy are sites which are remote from main electrical grids and which have favourable wind energy resources. These sites include places in southern Canada such as island locations, mountainous or wilderness sites. They also include many potential sites in the northern portions of our provinces and in the Yukon and Northwest Territories. Due to the remoteness of these sites, many additional problems arise which the WECS supplier and user must face. These problems include overcoming permafrost, dealing with low altitude extreme cold, handling the logistics of northern/remote transportation and equipment availability and facing the added costs which result. Canadians are facing these important problems and dealing with them using present skills and experience, as well as developing new technologies and ideas to overcome these difficulties.

INTRODUCTION

BIOGRAPHY

NESL has been around since 1980, operating from just out of Calgary in the rural community of Springbank.

I am a physical geographer, with a background in meteorology, hydrology and computing. I've been involved in wind energy since 1978.

Remote Sites Installed

My first WECS procurement experience was to participate in the selection and installation of a Thermax Helius Rotor in the Rocky Mountains of Alberta. Since then, we have sold or installed remote WECS for use on farmland, in the Yukon bush, on the front ranges of the Rockies and on acreage locations.

We have sold utility-connect WECS, remote battery charging WECS and WECS for hybrid use with diesels.

Arctic/Alpine Experience

I've worked in remote alpine and arctic locations for over a dozen years. This has included logistics of supplying camps, remote meteorological instrumentation sites, travelling by foot, skis, helicopter, ship, hovercraft, skidoo, 4 x4 and commercial airline. There are many difficulties involved with work of any kind in these areas, and I've experienced a few of them. These problems are sometimes obvious and solved by common sense, however this discussion forms a portion of a skeleton checklist which we use and may help prevent difficulties for other developers.

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[1] Nor'wester Energy Systems Ltd., Box 7, Site 32, Rural Route 12, Calgary, Alberta T3E 6W3

Other problems discussed here are more general and not specific to Northern/Remote situations, but still need to be brought up.

In this talk, I'd like to share a few of these things with you.

BACKGROUND

WHAT ARE REMOTE/NORTHERN SITES?

Define: Remote

Remote sites are those which provide difficult access, usually are not staffed, usually are not on or near the grid, and usually (but not always) have a "severe" environment.

Define: Northern

Northern sites are really all the ones in Canada! But mainly here I am talking about sites north of the highway system of southern Canada: the north portions of the large provinces, the territories and the offshore. Places like Churchill, Carcross, Resolute Bay or Sachs Harbour.

Both?

The real fun sites are those which are both northern and remote! Many in northern Canada are that, and that doubles (or worse) the problems discussed here today.

DISCUSSION ON PROJECTS TO DATE

This refers to Canadian experiences only and represents only a small survey of existing and past projects.

North

We have gained quite a bit of northern experience to date - enough to begin to identify and start to deal with problems. Some of the more well known ones are:

- Frobisher Bay

This was operated for a short time only. It was a VAWT built by Frontier Systems in Ontario. I saw it standing in recent years but I understand that there were bearing failures early in its life.

- Churchill

This is one of the 50 kW NRC/DAF VAWT units that has worked well. It looks similar to this one at Swift Current.

- NRC (Frederking)

Sections of the NRC which conduct work in the north requiring remote powering for instrumentation have used small Wincharger (Dynatechnology) units, sometimes cutting the blades down to compensate for high energy at low temperatures.

- SUNCOR (wecs-ice motion)

Suncor made their own WECS using Wincharger blades and adapted auto type alternators, storing the gel-cel batteries in the ice for warmth. I have two of these units which I have bought from Suncor.

- Bristol Aerospace

There was a famous VAWT built by Bristol in Winnipeg and used by ESSO that reportedly drifted into Soviet waters. It worked very well until out of radio range.

- Hall Beach

A utility connected WECS, built by North Wind, will be going into Hall Beach as soon as it completes testing at AWTS. It is rated at 9 kW.

- Cambridge Bay

As reported in the recent CanWEA newsletter, one Jacobs (and soon more) are operating as a utility connected WECS at this community.

- Polar Bear Pk

A Bergey 10 kW unit was installed at this remote community and operates in a battery charging situation.

- Sudbury

Although not everyone would consider this location northern, it has application. NRC and Ontario Hydro operated a VAWT with simulated load in mechanical and electrical interconnection modes for testing and research.

Remote

- Pigeon Mountain & Plateau Mountain

Some 5 years ago two North Wind HR2's were installed at these windy mountain sites in Alberta. They suffured nearly every type of damage possible, from lightning strikes to burned out generators and damaged slip rings. They continue to operate, however they were out for over 5 of the last 8 months.

- Christie Ridge

Last year at this time I reported on the installation for TransAlta Utilities near Pincher Creek. This unit suffered problems initially with blades which led to frame problems, but has operated satisfactorily since its "debugging".

- Coast Guard sites in BC(other places?)

The CCG reportedly has used numerous Dunlites and other earlier model WECS in remote applications near marine conditions for lights and Navaids.

- Other sites

Obviously there are many other examples of remote sites. I invite you, if there is time, to relate during the discussion period your experiences or knowledge of particularly successful or problematic remote or Northern sites.

WHAT ARE REMOTE/NORTHERN APPLICATIONS?

- simple battery charging
- battery charging with inversion
- battery charging with hybrid (diesel)
- not battery charging, but load feeding (heat)
- grid connected
- connected to diesel grid
- connected to diesel system itself
- stand alone grid

Science fiction at present date! Well, possible but not done and considered too expensive and tricky to contemplate at present.

THE PROBLEMS

FOUNDATIONS

There are problems in the north and in many alpine WECS sites with poor soils for foundations. These may include clays, loose shales and permafrost.

Foundations for WECS require compressive strength (to hold up towers) or tensive/anchoring strength (to resist guy cable pull out or overturning moment from a tower).

A variety of standard foundation practises may be used for clays.

Foundations in loose shales usually call for oversizing of foundations, so that shear strength is not a factor in resisting the overturning moment of a tower - rather the bulk mass of the foundation serves the anchor purpose.

In permafrost, whether continuous or discontinuous, foundation problems for WECS have not been so well solved. Simply put, disturbance of permenently frozen soils results in new types of heat transfers. This often causes melting, turning such soils into "gumbo" with resultant loss of structure and strength. Refreezing starts from the tops and sides and may take months to years to regain former soil strength. In some cases, melting continues into the surrounding soils and the site becomes unusable until the frozen conditions return. Solutions at present involve use of piles, "floating" foundation pads and insulation. NESL has been studying methods to quickfreeze the soils back to their natural state.

TRANSPORTATION

For People

There is only one practical means to move people in the North - by air. In many other locations which are remote 4 x 4's, manual methods or helicopters may be necessary. In all cases, specialized equipment, careful monitoring of weather and ground conditions and experienced operators are needed. Most solutions involve costs not usually found in other sites.

For Equipment (Cranes, Backhoes, etc)

Many northern and remote sites do not have contractors with various types of heavy equipment. Moreover, it is often impractical as well as uneconomical to bring in these pieces of equipment. The substitutions for cranes, backhoes, cats/dozers, even pickup trucks must be innovative and imaginative. Considerable thought and planning is required, as there are no repair shops, parts dealers or qualified mechanics in many locations.

If the decision is made to transport these types of gear to the site, it may mean long term leasing/purchasing and the methods may be very expensive. For example, in order to get large pieces of gear to many communities along the coast of the NWT, shipping must be booked on the annual SEALIFT up to a year before the shipping season. It has been common to find that pieces get accidently delivered to the wrong communities or "bumped" at the last minute for higher priority cargo.

For WECS Gear

WECS gear can be moved by ground, air or sea. As mentioned, use of SEALIFT requires long term planning and careful monitoring to prevent partial shipment or any losses.

Ground transport is only possible in certain situations, and may require specialized equipment. This is the most likely way for remote sites.

The use of air transport may be very costly, but may also be the only practical method. Matching of cargo to appropriate aircraft, and aircraft to the airstrip is required. For example, a Hercules aircraft needs a strip of nearly one mile, while a Twin Otter needs only 2000 feet. However, a Twin cannot take any cargo over twenty feet long or 2 tons in weight while you can drive large equipment into a Herc. Most available (affordable) helicopters are only capable of lifting 1000 lbs to 1 Ton.

Since WECS gear may require special handling, this aspect requires special attention and care.

TRAINED CREWS

Trained crews for work in the North or remote sites can be transported in, but at considerable cost. Crews may not be compatible with the situations they find themselves in, and may have trouble working in situations where spares, repairs, and home comforts are lacking.

The use of local workers presents special challenges and advantages. In many cases these people have special skills and talents which can be applied to projects, however they are unlikely to have specific knowledge of or skill relating directly to the work of installing and commissioning a WECS. Additionally, in some communities in the North the concept of "work" differs markedly from that in the South, and understanding, budgets and management must be prepared for this.

SITE ANALYSES AND WIND DATA

Many Northern communities have small airstrips or airports. The major ones include AES weather stations and maintain good records of meteorological parameters such as wind speed. However, many others have just a radio operator and wind sock. Most applications will require site instrumentation, with travel to the site and arrangements for data transfer.

A good reference and starting point for Northern applications is Wind Energy in the Northwest Territories [Janz, Howell & Serna report].

Remote sites are even more important: they will have no wind records and may well be in severe environments, requiring better than usual definition of turbulence, shear problems and extreme values of wind speed.

The use of dependable data logging equipment is essential. It makes little sense to use remote PV powered gear in the North in winter months, due to the constant darkness. Storage batteries for remote instrumentation may have to account for long term freezing temperatures and lack of access/visits; the use of gel-cels and satellite transmitters may be appropriate.

WORKING ENVIRONMENT

There is nothing quite like working outside at minus 37°C in total darkness for a week. Hopefully there will be no wind! There are real problems with using mittens with tools, no hoarding over work sites and getting up and down towers safely. Winter seems to be the time when most serious problems crop up.

Of course, there are advantages to working in summer during the 24 hour day, except for the flies and mosquitos (and the poor sleep most Southerners experience in this light).

COMMUNICATION

Just like all the rest, communications are not always easy at these sites. The use of radios at remotes sites, satellite-linked telephones (with one way voice) in the North, once per week mail and usually no telex complicates things. There is no problem with the technologies to bring good communication in, but it is very expensive. In some locations it is already remarkable - in the Yukon portable hand held telephone communication is a reality today, even deep in the mountains.

APPLICATIONS

Grid type systems

Problems with Diesels

Diesel systems with present electronics coupling technology are able to handle only about a 30% penetration by WECS systems. This is due to problems of responding to sudden changes in load or production related to WECS performance, resulting from changes in wind energy availability, loads variations and diesel operation programming.

Diesel systems do not like to stop and start often, and they run best at or near full generating capacity. This often results in control strategies which waste wind energy by controlling the ouput of the WECS.

Three vs Single phase

The use of one system over another depends on the applications and the communities. There are obvious advantages to 3 phase but transmission capabilities or other reasons may prevent its use. Matching the WECS long before delivery will prevent problems.

Battery type systems

Problems with Batteries

Battery systems are not yet perfect. They are expensive, heavy, cannot be shipped by all means and require maintenance, pose certain hazards, and may not always be as reliable as manufacturers claim. Distances from sources and other problems related here contribute to these problems, which must be considered.

Obtaining AC power: inverters, single vs three phase

Inverters are the obvious choice for remote AC power from battery systems, although in some cases, the use of backup fossil fuel generation may be warranted when only very occasional AC power needs are present. The backup serves that purpose, too. Inverters have dropped in price significantly over the last few years - down to about $1/w rating. Efficiencies have risen as well. However, these are sensitive electronic appliances and very remote use (for which they are intended) has shown users that they still occasionally need servicing, the reliability and efficiency is not always what was expected and different models certainly operate and succeed differently.

EQUIPMENT PERFORMANCE

Blades at Cold Temperatures & at Sea Level

As you are aware, rotors are matched carefully to other system components and to the general operating environment. Rarely, though, do these considerations take into account the remarkable changes in wind pressures at -40°C at sea level. Nor do they consider the materials changes and effects at those temperatures. Obviously there is more power available and likely less passive response in materials to stresses.

Generators and Overspeed in These Conditions

As Malcolm Lodge and others will tell you, increased power in these conditions will sometimes cause overspeeding and generator failure. Auto protection features seldom work as designed in this portion of the operating range. Anticipation of this sort of problem can prevent serious consequences. Operation strategies may have to consider and anticipate these conditions.

Bearings and Lubrication

The use of synthetic lubricants greatly helps northern and remote use: these remarkable products may allow infrequent site visits and they change viscosities throughout nearly all operating ranges. Reports from Alaska suggest that they do restrict 100% perfect operation at cold temperatures - and this may be an advantage, acting as a built in brake to prevent generator overspeed. In certain cases and for certain components, special consideration must be made for these difficulties.

Icing of Blades, Pitch Mechanisms, Yaw Mechanisms

I have not experienced problems with blades icing up (yet) but then most of our work is in very dry climates. However, we try to use black coloured blades in circumstances where we are concerned (it costs little to try and be safe in this way). In the north, unless in a marine situation, most applications will not likely find this a problem. However, even a small amount of hoar frost or icing (even from melt/freeze) may render a pitch or yaw mechanism unworkable and lead to damage. Protection, heating elements or other solutions may be necessary if this proves to be a serious problem.

Sensing and Control Equipment

I have certainly had anemometers frozen up and systems stopped as a result. The use of black coloured sensors may help where there is sunlight. Doubling up (redundancy) will also help, especially if two sets are in slightly different orientations or situations. Most regular control equipment has no problems but sophisticated sensors on large systems may be affected in unusual ways.

Towers, Guys, Anchors

Towers and guys ice up and become unclimbable. It is very dangerous climbing in mittens and impossible to use barehands at the top. Cold increases brittle failure possibilities for these components and may cause them to be more subject to vibration effects. Anchors and their components may be more affected by vibration at low temperatures. Tilt down systems, we have found, have some real advantages.

Winch Systems (if applicable)

Recently we experienced a classic failure of a gas driven winch system which had inadvertently been left outside at -15°C. It didn't work and our intensive attempts caused a valve failure leading to $75 of repair. Trivial, except that it had to be carried out by hand (!) through 50 cm of snow at 6000'(1800 m) altitude. Other problems with these systems can include icing of pulleys, winch drums, cold temperature failures with dogs and brakes or gears, lubrication systems. Winch systems and tippable towers are a great advantage in remote sites but also need special attention and care.

Costs

It goes without saying that costs can be high. It always takes a little more time and a few more people in these situations. Typical accomodations in northern communities are $120 to $150/day. Sometimes this includes meals. Vehicle rentals, if possible, are typically $75 to $100/day. Rental of equipment is typically two to three times southern rates. Fuel is often double. Labour rates vary, but you must often compete with high paying southern employers. Transportation costs to the north, especially with de-regulation, are very high compared to southern ones. The additional communications used to avoid the other costs listed also lead to higher costs for communications.

- Rentals
- Accomodations
- Food
- Labour
- Transportation & Communications

THE ADVANTAGES

- APPARENTLY LOTS OF WIND IN MANY SITES
- SEA LEVEL AND COLD GIVE LOTS OF POWER
- IDEAL APPLICATIONS CONSIDERING USE OF DIESEL
- ECONOMICS OFTEN LOOK VERY GOOD

SOLVING THE PROBLEMS

EMR's R&D Budget

Although the EMR R&D budget is significantly reduced from the NRC version, it is a brave start. The summarized proposals for this are now out in draft form, and they mostly reflect the recommendations from industry and experts. Certain important recommendations are not included at this stage. However, more funding is needed, and close lieson between EMR and industry is needed. This technology, by its nature and its support, is made up in industry of diverse experts and firms, and the provincial and private utilities are not likely to be major users, compared to individuals and small business. Guidance from industry and user groups, such as the SPPAA and Ontario SPPA, is required.

Participation from U.S. and Foreign Manufacturers

There is already considerable activity by foreign interests. This has been beneficial and has allowed the industry to limp along, despite FST and import duties. More will be required and should be supported, in conjunction with the development of Canadian modifications and technology developments suitable to our applications. Why re-invent the wheel? Let's adapt it, but ensure that we get the credit and the profits for doing it.

Committment by Federal Government to Try/Use WECS in North

There is a very serious need for the Federal Government to set a policy requiring serious consideration of WECs and other renewable energy technologies for sites in remote and northern regions. To this end, the policies of NCPC, the utility in the North, need revision. Coast Guard, DND, DPW, and other agencies must examine, seriously, the use of wind and other energy sources. This will help us to develop experience and expertise and will allow the industry to grow, stabilize and gain a footing which will give us World standing in expertise in this particular area: northern and remote WECS expertise.

Work by Canadians to Adapt or Create Technologies to do Job

We have solutions on the way or in trial now for many of these problems. These solutions are coming from field use and user feedback - from small power producers and industry service/maintenance people. But we need support and we need to help ourselves.

We need to work! We need to come up with ideas, get funding or fund them ourselves and get these problems solved. If we don't, someone else will - from Alaska, from northern Europe or other places. We have the need, the market and the industry. We can do it and we can start right now.

Go out and get EMR funding. Get IRAPS. Get contracts in the North or in remote areas. Do the R&D. Attract venture capital.

Let's use our problems and our needs to our advantage.

CURRENT AND FUTURE PICTURE

The sites up at present are a good start. There have been problems and we have learned a lot - in some cases there is still more learning going on! We need this experience and these paths to confidence.

There have been a few announced projects: Magdelan Islands, for one. However, there are many major northern communities, there are new DND RADAR sites and there are new sovereignty bases coming in the north.

EMR has announced that there will be RFP's on the way as a result of the work of many here today in advising them. Make sure we work hard on these and get the best work done - for all. All of the problems listed here today need work. If you don't see an RFP but have a good idea, go for the UP route (DSS & EMR will help).

One of the most important problems, not mentioned specifically in the context of this paper, but necessary in any discussion of Canadian WECS industry, is the so-called "LEVEL PLAYING FIELD". It is VITAL that we gain similar footing to other energy technologies - their advantages, their tax breaks/credits, their accounting procedures, their loan situations and capitalization advantages and their pricing capabilities. We need to compete with them on this level playing field, and it is our - and the governments - responsibility to ensure this.

CONCLUSION

- CANADA HAS A MARKET FOR WECS IN REMOTE/NORTH
- EXISTING EQUIPMENT AVAILABLE IS NOT YET PERFECT FOR THIS
- SOME GOOD EXPERIENCE WITH POSITIVE RESULTS EXIST
- WE MUST BE THE ONES TO ADAPT/CREATE THE NEW TECHNOLOGY
- WE CAN DO IT - WE WILL DO IT - WE ARE DOING IT!
- THESE PROBLEMS ARE OUR ADVANTAGE, AND WILL RESULT IN UNIQUE CANADIAN CAPABILITY

REFERENCES

Janz, B., D.G. Howell and A. Serna. 1982. WIND ENERGY in the Northwest Territories. Science Advisory Board of NWT. 108pp.

DEMONSTRATION AND TESTING OF WATER PUMPING WIND TURBINES

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In 1982 the Drainage Branch of Alberta Agriculture and Jensen Engineering Ltd. of Olds, Alberta, in conjunction with the Alberta Research Council, initiated a study to evaluate the use of wind turbines in Alberta to pump water and monitor, demonstrate and evaluate various wind turbines distributed in Canada. To meet these objectives a test site was established adjacent to a St. Mary River Irrigation District canal immediately east of Lethbridge, Alberta and a total of six different water pumping windmills were installed during the spring of 1983.

This paper briefly describes the test site, the monitoring equipment, and the wind turbines tested.* The performance results are presented and used to illustrate various applications of the wind turbines. Finally, an economic analysis is performed for the Alberta situation.

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*From report for Alberta/Canada Energy Resources Research Fund, Report #89, "Evaluation of Low Volume Wind Turbines for Pumping Water," Patterson, Baker and Jensen, 1985.

For further information, please contact David Baker at (403) 239-4100 or (403) 239-0750.

Note: The full paper was not available at time of printing.

DATA ACQUISITION SYSTEM FOR EVALUATION OF INDAL TECHNOLOGIES' SERIES 6400 VAWT AT THE ATLANTIC WIND TEST SITE

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ATLANTIC WIND TEST SITE

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NATIONAL RESEARCH COUNCIL

CANADIAN WIND ENERGY CONFERENCE '85
DECEMBER 9 - 10, 1985

DATA ACQUISITION SYSTEM FOR EVALUATION OF INDAL TECHNOLOGIES SERIES 6400 VAWT AT THE AWTS

E.R. SMITH J.G. KELLER

Summary

Project Aquilo is a major project sponsored by the National Research Council to test and evaluate design, performance, and reliability of a 500 kW vertical axis wind turbine designed and built by INDAL TECHNOLOGIES of Mississauga, Ontario. To accomplish this, a complete data acquisition system with software was developed. This system has proven to be a powerful tool in the evaluation of the wind turbine. The system can collect up to 40 channels of data at 100 Hz scan either in a "burst" mode or on a continuous basis. Binning and monitoring programs provide quick performance and evaluation data from the machine which is essential for assuring safe operation and for guiding continued testing of large-scale prototype equipment.

Keywords

Data acquisition systems, testing wind turbine, instrumentation/ evaluation.

Introduction

Project Aquilo is a major project undertaken by the National Research Council to test and evaluate the design, performance, and reliability of a 500 kW vertical axis wind turbine designed and built by INDAL TECHNOLOGIES INC. of Mississauga, Ontario. To accomplish this thorough testing, NRC developed a data acquisition system with appropriate software which could analyse and display data immediately to the test engineers in easily readable form. This paper text briefly describes the objectives, criteria and results of the development exercise. Quantitative data from the AQUILO tests are used to illustrate the capabilities of the data system and its associated software.

Objectives

To evaluate a prototype wind turbine such as the 500 kW DAF VAWT, a sophisticated instrumentation and data acquisition system had to be developed, not only to measure and record various signals, but also to do on-site and remote analyses of these signals.
The system was to be able to:

- Record and bin low frequency data (5 Hz max.) from a limited number of channels (10) for the measurement of the performance and the confirmation of the theoretical power curve for the machine.

- Record and later analyze on site, high frequency data (50 Hz) from up to about 40 strain gauges mounted on the rotor structure.
- Provide to the user all the various conditioned signals in standard voltage ranges for connection to FM tape or chart recorders.
- Allow interrogation and analyses of data from Ottawa via a telephone link.

Also,

- The signals should be high quality (high signal-to-noise ratio) to ensure clean and reliable results from the measurements.
- The sensors and front-end components must withstand typical maritime environments with precipitation, icing, salt spray, and temperatures ranging from -25°C to +30°C.
- The system should be "portable", allowing it to move via a van to other turbine sites.
- The system software and measurement equipment should be easily adaptable to other wind turbines both on-site at AWTS and from remote sites via FM tape.
- The system should include software to analyse blade/structure stress measurements, power conversion efficiency and meteorogical measurements.

The above objectives were carefully analysed to best fit them into a data acquisition system.

System Description

Reference 3 describes in detail the design methodology undertaken to establish the system architecture necessary to achieve the stated objectives. Reference 4 provides particilar details on the selection, application, connection and calibration of strain-gauges on wind turbine rotors. A brief overview of the complete instrumentation/acquisition system follows.

FIGURE 1 shows the block diagram of the system. The data system permits selection of 25 high priority signals which are recorded as part of all data sets. Typically wind speed, power, torque, guy tension, a few operational parameters, and certain key strain-gauges are assigned to this group. The remaining 15 channels are used primarily for strain-gauges. Strain-gauge signals use shielded twisted pairs which in most cases are run internal to the extruded aluminum blades, providing a well-shielded low noise environment. Amplifier cards are mounted firmly in a waterproof box at the base of the rotor to amplify the signals by 1000 (~1 psi/mV for measurements on the aluminum blades). Because of the large number of strain gauges, the signals are then divided into two groups, A and B.

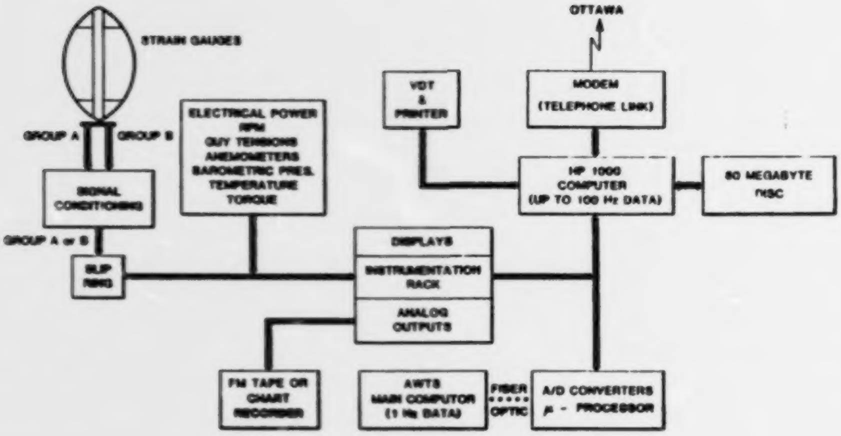

STRAIN GAUGES
GROUP A
GROUP B
SIGNAL CONDITIONING
GROUP A or B
SLIP RING
ELECTRICAL POWER
RPM
GUY TENSIONS
ANEMOMETERS
BAROMETRIC PRES.
TEMPERATURE
TORQUE
DISPLAYS
INSTRUMENTATION RACK
ANALOG OUTPUTS
FM TAPE OR CHART RECORDER
AWTS MAIN COMPUTOR (1 Hz DATA)
FIBER OPTIC
A/D CONVERTERS
μ - PROCESSOR
VDT & PRINTER
OTTAWA
MODEM (TELEPHONE LINK)
HP 1000 COMPUTER (UP TO 100 Hz DATA)
80 MEGABYTE DISC

FIGURE 1: AQUILO INSTRUMENTATION BLOCK DIAGRAM

Signals from the main control building switch relay contacts to send one of these two groups of signals through instrumentation slip-rings in the stub shaft, and through buried shielded cables to the main control building. An instrumentation rack in the building allows easy access to the analog signals via BNC connectors. This rack also contains signal conditioning for the guy-tension gauges, the anemometers, and wind direction sensors. Digital and analog displays indicate wind speed and direction, barometric pressure, temperature, power produced/consumed, and high speed shaft RPM. From the rack shielded lines go to the HP 1000 high-speed data acquisition computer and to a microprocessor which transmit selected 1 Hz data to a monitoring computor in the AWTS main building.

Eight BNC connectors on the rack allow quick patching of signals not normally measured into the data acquisition system. This allows both the analysis of FM tape data from other wind test sites and a quick look ability at problem areas during trouble-shooting exercises.

The high-speed data acquisition computer consists of a HP 1000 A700 computer. This is a multitasking computer which allows the system to do analysis while taking data at different rates and possibly to accept inputs from more than one wind turbine. The measurement system scans the 40 channel inputs at 14 kHz. The software programs are programmed to then read the data channels (selectable) at a rate between .1 and 100 Hz. This set-up reduces skew error between channels to an absolute minimum. Storage of data can either be on the 80 megabytes of disc storage or on a streaming tape cassette facility which is also available. Each 600 foot tape allows up to 64 Megabytes of storage. The large disc space allows extended periods of unattended data taking as well as ready access to several files during analysis.

The terminal at the site has a built-in printer for quick hard copies of graphs and data. The telephone modem link allows interrogation by terminals located at NRC as well as electronic data transfer ability to other computers. Both monitoring and analysis can be carried out by a terminal in Ottawa. This has been a most valuable tool during initial high wind conditions on the machine.

Software Description

NRC benefitted considerably in the development of software for testing medium-sized WECS by obtaining a set of data acquisition programs from Sandia Laboratories in Albuquerque, New Mexico. Sandia have been testing wind turbine structures, especially the vertical axis types for some time. The programs at Sandia Labs were developed for a single-task single-user HP system of a much older design. Working in conjunction with DMR Associates of Ottawa, the original programs have been modified to run on the HP 1000 A700 system to take advantage of a multi-user, multi-task operating system, (this operating system is called RTE-A). The programs have been evolving throughout the test period; improving format, capabilities, and ease of operation. As "guid-pro-quo" NRC has provided copies of the recorded and upgraded programs back to SANDIA for their newly-acquired multi-tasking computer.

The software can best be divided into data gathering and data analysis programs, both of which require calibration information to provide identification and quantitative scaling of each channel.

Calibration Data: ADCAL

Most of the programs used on the data system ask the operator for the calibration file which stores the gain factors, zero offsets and channel units. This table can be changed at any time to correct for, say, drift in stress measurements. Several different ADCAL files can be stored and recalled depending on the particular configuration. This allows different wind turbines to be interfaced easily into the data acquisition system. For example, Aquilo has normally two tables, one for each group of strain gauges. The Adecon machine which normally inputs data through FM tape also has its own Adcal table. This allows more than one machine to be tested at the same time through use of the computer's multi-tasking capabilities.

Data Gathering Programs

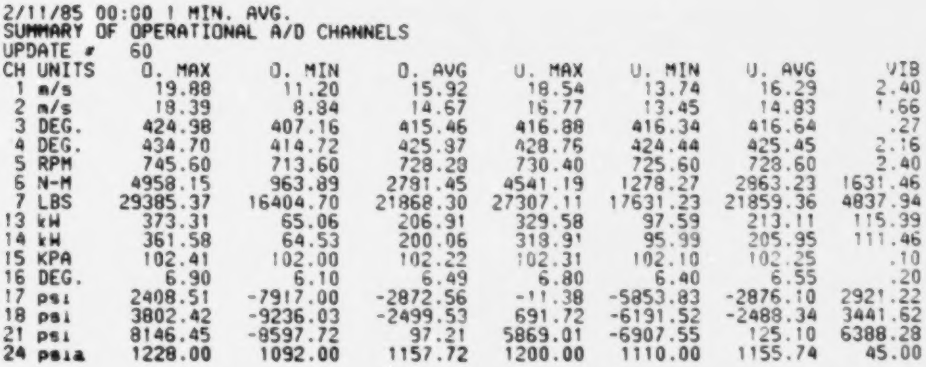
There are three modes of data gathering; on-line monitoring, time-series storage, and on-line binning routines.

ON LINE MONITORING: "FAST"

"FAST" is the program name used to initiate data to be displayed on the terminal screen for on-line monitoring. The number of channels are selectable and the data rate is fixed at 5 Hz. FIGURE 2 shows a typical screen display using this program. The first column describes the channel numbers and appropriate units that are being monitored. The next two columns record the overall maximum and minimum points seen by the 5 Hz acquisition from the commencement of the FAST Routine. The next column records the overall average value of each channel from the commencement of FAST. The next four columns record the most recent data. This data reflects each channels' maximum, minimum, average, and vibratory or peak readings for the most recent time period selected by the user during program initialization. Figure 2 illustrates an example of the FAST terminal output. Here the program has been running for an hour so overall data values are calculated for the hour. The update time period selected was 1 minute so the last columns indicate values of maximum, minimum, average, and peak for the data during the last minute.

The vibratory or peak value is the maximum value minus the minimum divided by two for the most recent data set.

The FAST program can also be run on stored time series files to give a quick indication on whether data contained in the file is of interest or for categorization of data (high, low wind etc.).



```
2/11/85 00:00 1 MIN. AVG.
SUMMARY OF OPERATIONAL A/D CHANNELS
UPDATE #    60
CH UNITS      O. MAX      O. MIN      O. AVG      U. MAX      U. MIN      U. AVG         VIB
 1 m/s         19.88       11.20       15.92       18.54       13.74       16.29        2.40
 2 m/s         18.39        8.84       14.67       16.77       13.45       14.83        1.66
 3 DEG.       424.98      407.16      415.46      416.88      416.34      416.64         .27
 4 DEG.       434.70      414.72      425.97      428.76      424.44      425.45        2.16
 5 RPM        745.60      713.60      728.28      730.40      725.60      728.60        2.40
 6 N-M       4958.15      963.89     2781.45     4541.19     1278.27     2963.23     1631.46
 7 LBS      29385.37    16404.70    21868.30    27307.11    17631.23    21859.36     4837.94
13 kW         373.31       65.06      206.91      329.58       97.59      213.11      115.39
14 kW         361.58       64.53      200.06      318.91       95.99      205.95      111.46
15 KPA        102.41      102.00      102.22      102.31      102.10      102.25         .10
16 DEG.         6.90        6.10        6.49        6.80        6.40        6.55         .20
17 psi       2408.51    -7917.00    -2872.56      -11.38    -5853.83    -2876.10     2921.22
18 psi       3802.42    -9236.03    -2499.53      691.72    -6191.52    -2488.34     3441.62
21 psi       8146.45    -8597.72       97.21     5869.01    -6907.55      125.10     6388.28
24 psia      1228.00     1092.00     1157.72     1200.00     1110.00     1155.74       45.00
```

FIGURE 2: SCREEN DISPLAY FROM "FAST" PROGRAM

TIME SERIES DATA TAKING: "TSWR"

This task allows the user to select both the particular channels and the frequency at which they are scanned.

The sampling frequency range is from .1 to 100 Hertz. The length of the time series taken is user-selectable and can also be made continuous. In the latter case, the program automatically creates a new file every two hours and stores the previous file. When the disc becomes full, the program automatically purges the oldest file on disc to make room for new files. Files are automatically named by a date, time of start, file identifier, and sample rate code. This way common time series files can be located to automatically link them for plotting and binning programs.

BINNING METHOD OF DATA GATHERING: "BMFC and CBIN Programs"

Power conversion efficiency and statistical information can be best gathered by binning parameters with respect to other parameters such as wind speed blade tip-speed-ratio etc.

The program "BMFC", (BINS MASTER FILE CREATE) allows the user to set up the parameters and wind turbine data required for the bin method of gathering data. This file is then used to bin the appropriate data. Information used in this file include such parameters as rotor rpm, radius, swept area, wind speed channels and the wind direction binning is valid, shear correction, power and torque channels, tachometer channel, and finally the temperature and barometric channel. The user also selects the frequency at which data is gathered and the number of points to be averaged before binning. There are 60 bins each representing .5 m/s wind-speed. Statistical data is calculated and stored for the data in each bin.

Once the master file is created the user can start binning using the CBIN, (CREATE BINS) program. The are two choices for binning; the program can bin from real time data or from time series files selected by the user. When binning real time data bin files are created each day automatically and stored under codes identifying them by date and the bins master file. This allows elimination of data if unforseen circumstances have biased the data (ice storms, bad sensors, etc.). It also prevents the lost of extended data should there be a power failure (which is quite common at the PEI site).

Data Analysis Programs

PLOTTING TIME SERIES DATA: "PLOTW"

Any two channels plus a wind speed channel may be plotted versus time. Each channel is either automatically scaled by the computer according to minimum and maximum values or by the user. The wind speed channel axis is fixed, however, at 0-30 m/s (unless, of course, it is selected as a data channel). A maximum of 1000 points is plotted for each graph thus the program plots every nth point depending on the sample rate and length of

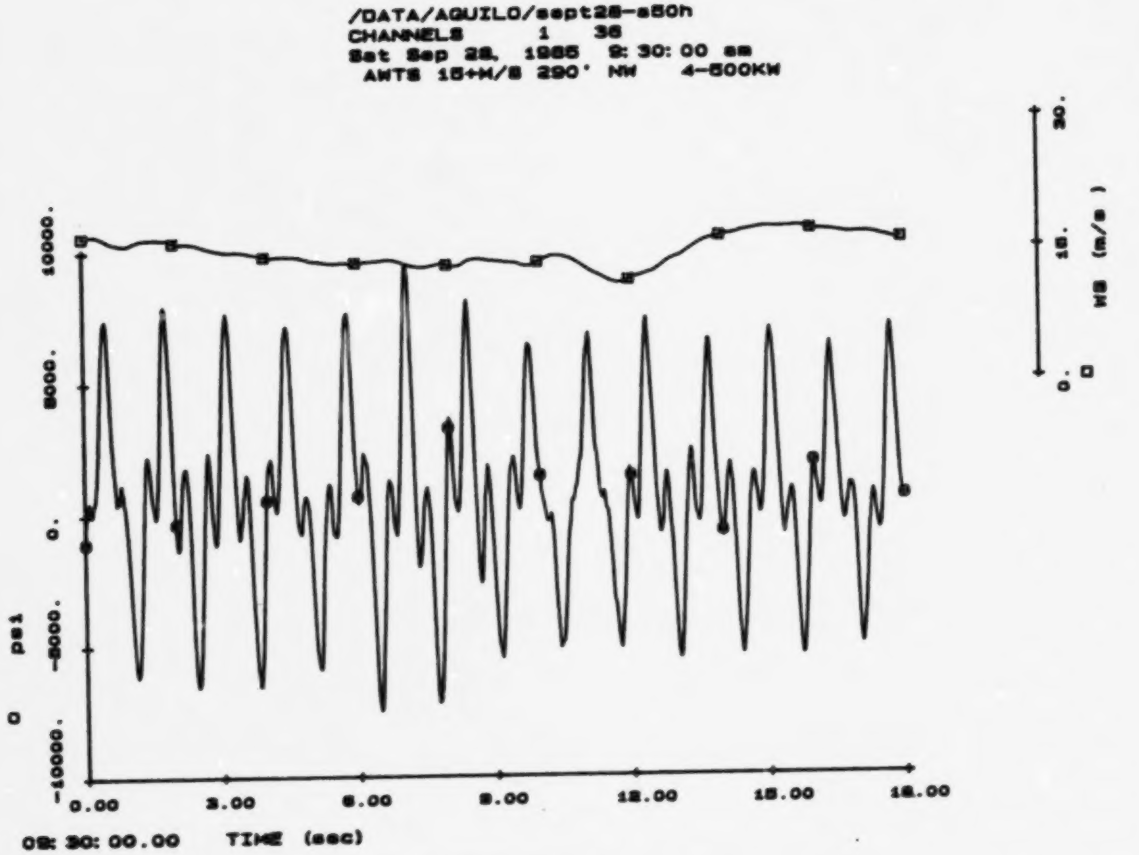


FIGURE 3: EXAMPLE OF PLOTW WIND SPEED AND COLUMN IN-BLADE STRESS

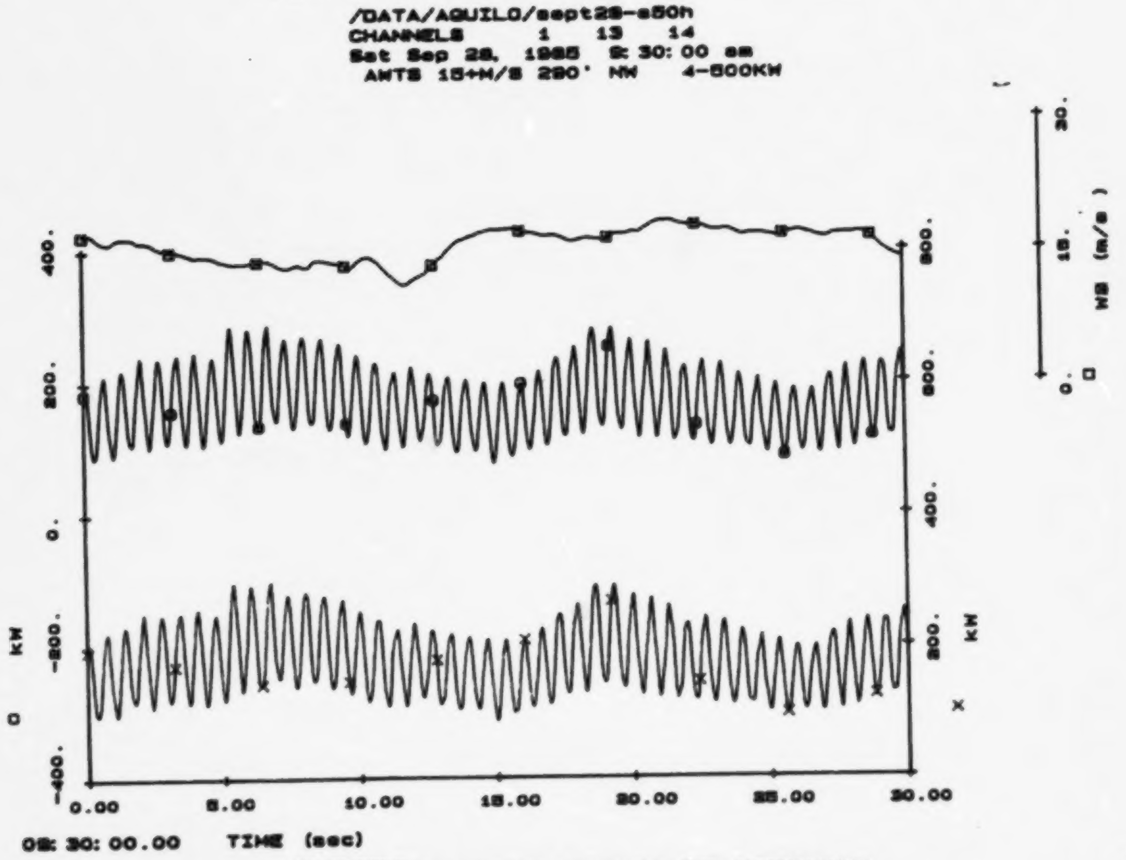


FIGURE 4: PLOTW GENERATOR OUTPUTS AND WINDSPEED

time requested by the user. The plot length can vary from a second or less to tens of hours by linking the time series files. This same feature allows the user to prompt continuation of the plot in which case the program selects the next section of time and plots it. This allows the user to search for and plot specific areas of the time series file.

Figure 3 illustrates the format of a typical time series plot; the windspeed and the rotor column in-plane stress on Aquilo. Figure 4 plots the two generator output powers. The VAWT torque ripple can be clearly seen in this plot.

SPECTRAL ANALYSIS PROGRAM: "SPCTW"

Spectral analyses can be performed on any specified channel in a time series file. Either amplitude or spectral density may be plotted against frequency. The program allows printing of all peak values and corresponding frequencies over a user-specified limit.

The program is quite flexible and allows the operater user to "zoom in" on specific frequencies of interest for plotting, keeping in mind the Nyquist criterion must be adhered to, (sampling rate must be at least twice the highest frequency of interest). It also allows automatic plotting of several channels at several different time periods for quick analysis. Figure 5 is a typical spectral amplitude plot of the column in-plane stress at wind speeds of about 17 m/s.

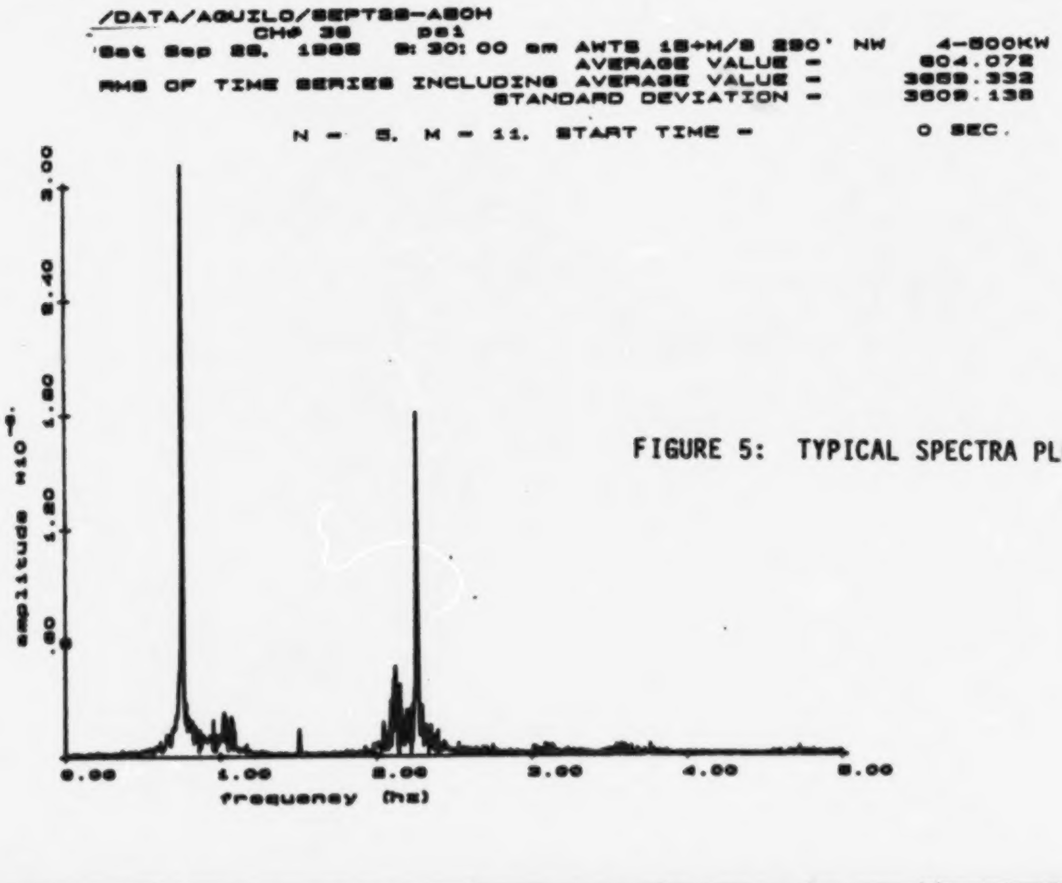


FIGURE 5: TYPICAL SPECTRA PLOT

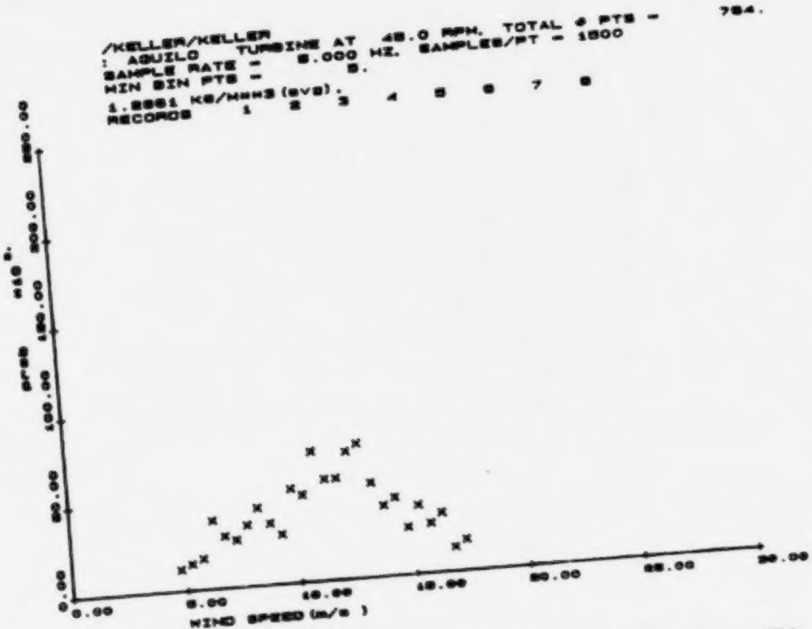


FIGURE 6

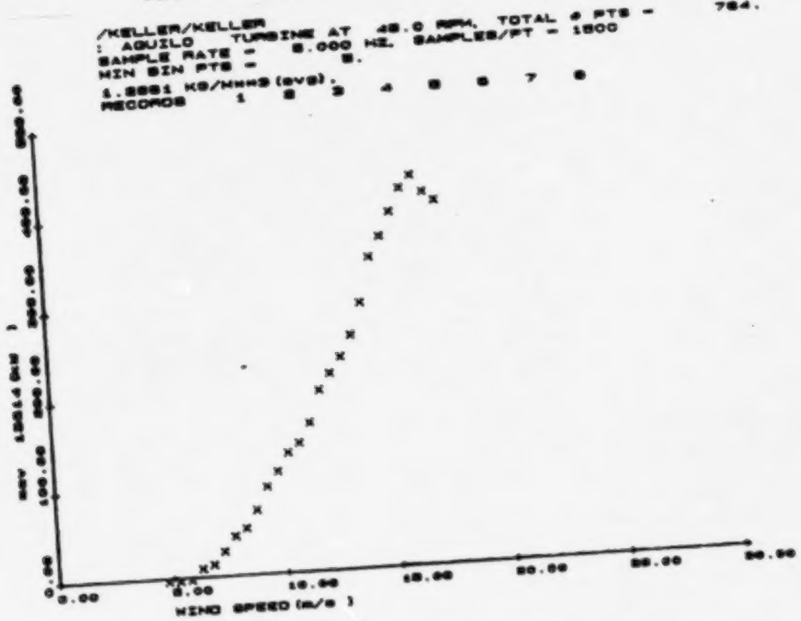


FIGURE 7

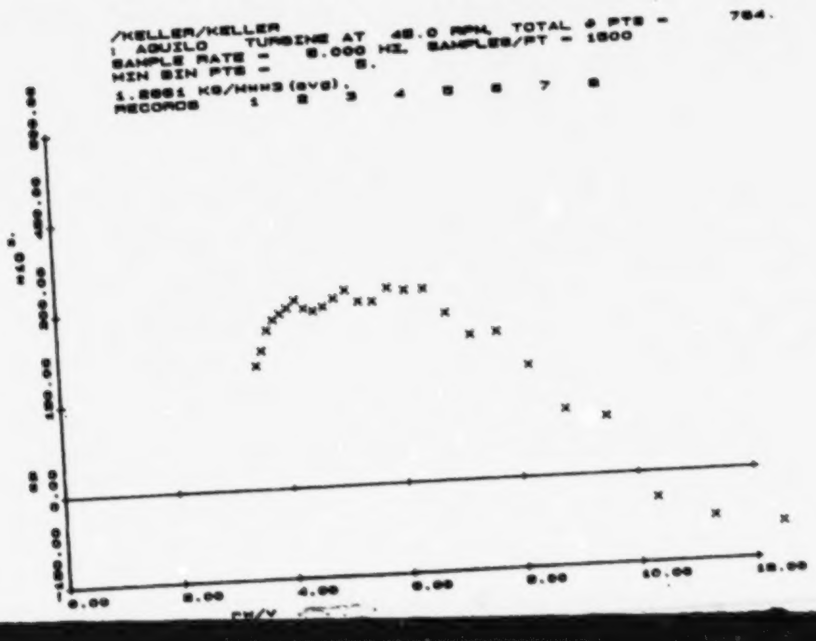


FIGURE 8

DISPLAYING BINNING RESULTS: "BINP"

This program displays the results of the bins program. There are many possibilities of plotting in this program. Binned channels can be added together or cross-binned, and different binned records can be combined to create a large binned file. Some of the more common plots used are the wind histogram plot as shown in FIGURE 6, the wind turbine power curve plot as shown in FIGURE 7, and the power efficiency (Cp) vs. blade tip speed ratio (λ) curve shown in FIGURE 8. Please note these curves are for illustration only and have been created using a limited amount of data with no air density correction.

Experience

The data acquisition system has proved to be a powerful asset not only in structural analysis and performance evaluation but as a diagnostic tool for investigating control faults and sequences of shut-downs. The measurement system has proved very reliable and extremely stable. FIGURE 9 shows the level of noise on the system. This is a spectral plot of a typical stress channel (rotor column in-plane) scanned at 50 Hz. The 60 Hz noise (which is the most significant noise problem) in this case aliases at exactly 10 Hz. The enlarged spectra shows this noise level to be less than 20 psi compared to a signal strength of 4000 psi. The resulting signal to noise ratio is better than 45 dB.

The software/computer side of the system has also proved itself repeatedly. Gauges can be automatically zeroed and gains corrected using the terminal. Structural informaton can be quickly obtained and analysed. This has been the case for both the 500 kW Indal Technologies machine and the 125 kW Adecon machine. Ref. 1 and 2 contain results and analysis using this data acquisition system.

The system has been extremely reliable and accurate compared to previous systems employed in wind energy research. NRC and AWTS personel have gained a huge amount of experience on wind turbine analysis using this system and have used this knowledge to streamline the original software and simplify the design of both the existing and future data acquisition systems which might be employed. Next year the system will move to Project EOLE, the 4 MW turbine being constructed at Cape Chat where it will help in the evaluation of that wind turbine system.

Conclusions

The multi-tasking computer concept for data acquisition has proven to be a powerful tool. It allows on-site data reduction, analysis and evaluation as well as simultaneous remote interragation by other scientists. Signals can be calibrated and zeroed from the warmth of the computer room and erroneous signals can be seen immediately by the scientist. The system has consistantly proven to be an asset in the evaluation of wind turbine systems and to date has been used to investigate problems on machines ranging from 8 kW to 500 kW.

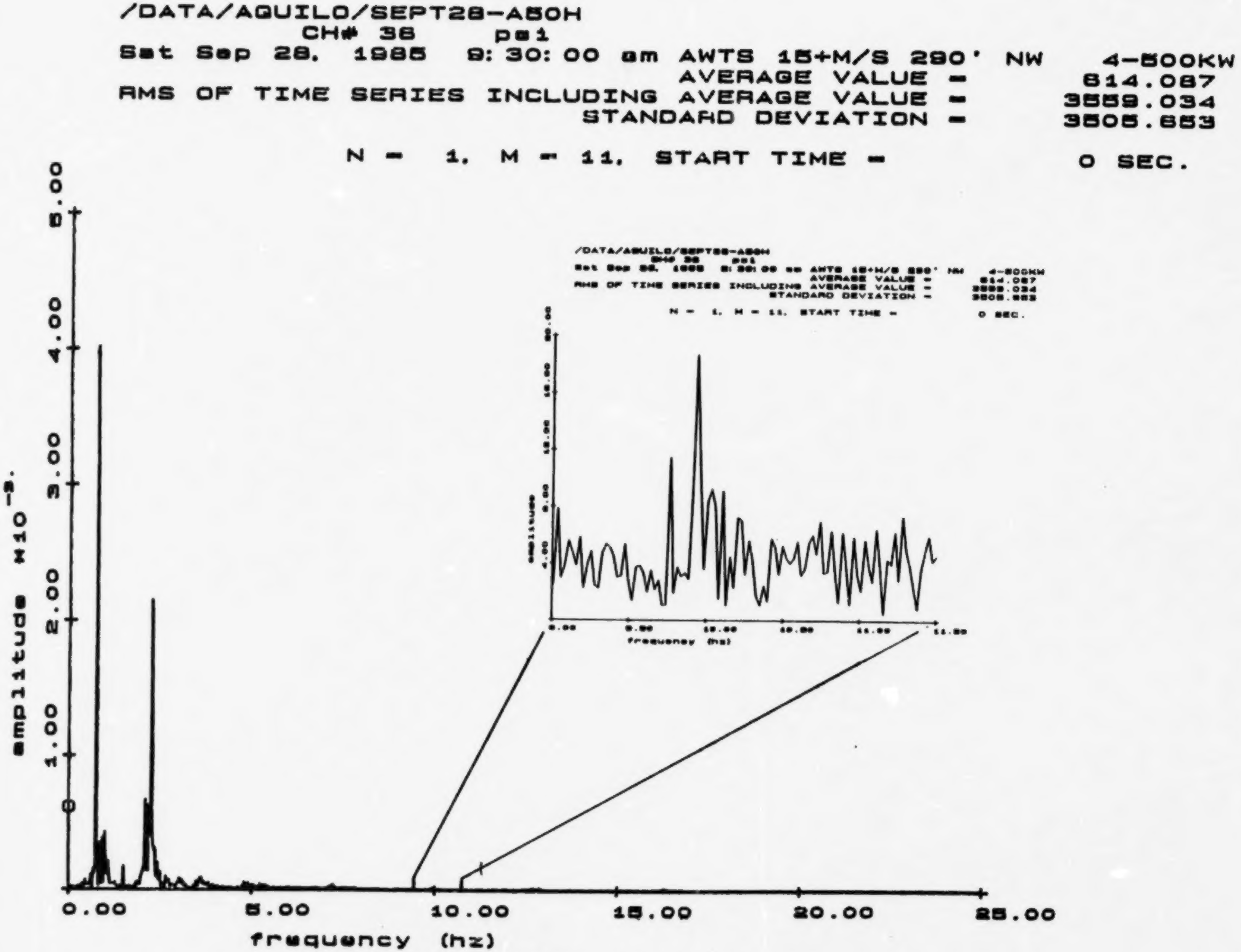


FIGURE 9: SPECTRA SHOWING NOISE LEVELS ON DATA SYSTEM

Acknowledgements

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A PERSPECTIVE ON THE DEVELOPMENT OF A WIND INDUSTRY IN CANADA, 1986

PREPARED FOR THE FIRST CANADIAN WIND ENERGY ASSOCIATION CONFERENCE, OTTAWA, DECEMBER 1985

CHARLES B. WALKER
MANAGER, E.I.S.I.

CRITERIA FOR DEVELOPMENT OF NEW ENERGY RESOURCES

At this point it may be useful to examine the criteria by which to judge the feasibility of and to arrive at a proper decision regarding the public need to commence community development of WIND ENERGY SYSTEMS in Canada to supplement our current resources of electricity from COAL, HYDRO AND NUCLEAR ENERGY. An important variable in this process is the need to recognize the continuing exhaustion of FOSSIL FUELS in Canada and throughout the rest of the world. WIND, SOLAR AND HYDRO, on the other hand, are self-conserving since they merely exploit the day to day passing energy from the sun and the flow of wind and waters.This is an important exercise to carry out because of the overwhelming dominance of FOSSIL FUELS in the current world economy, and the strong dependency of our Canadian industry, commerce and day to day social life on these energy sources.

I believe it may be stated as a generality that, with fossil fuels, it is only economically feasible to develop an energy source if the means adopted to recover, manufacture and process the new energy created DO PRODUCE A SUPPLY OF ENERGY THAT WELL EXCEEDS THE AMOUNT OF ENERGY INVOLVED IN ITS INITIAL PRODUCTION AND BRINGING IT TO MARKET. A simple illustration of this thesis is that recovery of barrels of oil from a tanker sunk in the deep ocean would probably be uneconomical at today's fuel prices. A more marginal example would be deep underground mining of oil-drenched shale which would require extensive pulverization and extraction of oil under pressure from the resulting sludge. Safe storage of the residual sludge would add a further deterrent to such a project. If we apply such criteria to the present world reserves of fossil fuels, it may well be that the reserves of ECONOMICALLY RECOVERABLE FOSSIL FUELS fall well below the current reserve figures usually quoted.

It is equally important to apply such criteria to the field of Wind Energy. Here, some dominant variables are:

1) SITING. This includes not only consideration of the optimum access to prevailing winds but also a minimum of rotational loss due to topography causing turbulence,drag effects etc.

2) RESPONSIVENESS: This means optimal design to enable the turbine to be sensitive to available wind flows and to develop maximum rotary thrust with a minimum of friction

3)CRAFTSMANSHIP: This means optimal construction and durability of the rotor,supports and driving mechanisms to enable the turbine to be sensitive to the varied wind and weather conditions encountered (e.g. icing, intense cold or heat,etc.) and tough enough to withstand the stresses involved.

Further considerations should include:

1) The optimum size of WIND FARMS to achieve targetted production levels

2) The saleability of energy produced and ease and cost of delivery to reliable customers.

3) The acceptance of the wind company and its operations by nearby communities.

4) The necessary period of performance required in order to pay off the initial capital costs of the turbine system

5) The cost of the continuing maintenance and replacement of parts..

6) An adequate source of wind to induce rotation in energy effective turbines.[In this context, it is important to recognize that Wind and Solar Energy resemble Hydro in terms of their requirements for dedicated use of large blocks of land in order to generate adequate supplies of electricity. In view of the current estimates that 70% of Canadians will be living in the four largest Metropolitan Areas in Canada by the year 2000, such use of land would appear to constitute an attractive potential investment of public and private funds on a long-term basis.]

7) Awareness of Uncontrolled weather variables: These include hurricanes, tornadoes, earthquakes, conflagration and volcanic eruption. For example: During the 1750's, a five year forest conflagration burned out the central forest area of Labrador blanketing the Maritimes in soot and fog. In 1881, Krakatoa, a pacific Island, blew up in an eruption that strewed sufficient dust into the atmosphere to bronze the sunsets of the world over the succeeding 5 year period. When the Mexican volcano erupted recently, it caused the prevailing southern westerlies in the Pacific to blow southeasterly. The eruption of Mount Helen recently threw a dust pall into the upper atmosphere in Canada. The resulting clouds did cause a drop in average summer temperatures across the south of Canada.

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THE CALIFORNIA EXPERIENCE

We owe a great deal to the initiative taken by the government of California to go for broke in the development of a practical test program for development of wind turbines on a quasi-economic basis. I am sure that other speakers will cover in detail the impressive record of electricity delivered during the past four years, equal to a small nuclear power plant, and the associated developments in design, durability and performance. While the program was subsidized, many of the constraining problems were overcome and the engineering capabilities vastly improved. From these experiments, which involved a great deal of european technology as well, it is now practical for Canadians to move with the times and begin to apply these technologies in a practical manner.

THE CANADIAN TRADITION - THE PUBLIC PROFILE

For some reason, our public perception of wind turbines is childlike. We enjoy seeing token windmills on baby carriages or old wind towers on old farms which no longer pump water. The new models of turbines are carefully consigned to remote areas where their presence couldn't possibly disturb any nearby residents or provide a target for young tower climbers. It is also true that many power stations and hydro facilitiess also operate in similar seclusion, largely, I suppose, because their product, electricity, is much more interesting at the end of the power line than at its point of origin. On the other hand, the public absorption with the consumer products operated by electricity is enormous: television, radio,VCRs,stoves,vacuums and other household choreworkers, electrical kitchen gadgets phones and tape recorders, all are objects of great interest and pride to the average householder but the power which operates these technological marvels is simply taken for granted.

THE CANADIAN ENERGY INDUSTRY - THE PUBLIC PROFILE

In 1979, according to figures compiled by the World Bank,(1), the average amount of energy used in industry and in the community, per person in Canada,was equivalent to 13,500 Kilograms of coal(their unit of reference). This figure is higher than for any other country in the world. (Norway ranked second with 12,000 and U.S.A. ranked third with 11,700). Canada ranked second only to U.S.A. in the number of cars in relation to the population: 2 persons out of every 3.

These figures should not surprise us considering the winter climate in Canada and the vast extent of the country that is much less densely populated than most other developed countries of the world. It does however highlight the importance of adequate energy supplies to maintain the country's growth and well-being.

In order to sustain the country's growth, the energy industries have proliferated and developed rapidly - particularly in the last 50 years. Gone are the days of primary dependance on carboniferous fuels in favour of oil,gas,coal and electricity for heating, cooling and industrial use. Gas and oil, including heavy oils, dominate the transportation field.

While renewable energy sources such as the sun, wind and biomass have received token attention, more effort has been put into energy conservation through proper building design, more than adequate insulation, temperature control mechanisms and energy recycling.

FUTURE ENERGY GROWTH IN CANADA

According to world figures compiled by the National Energy Board,(2) Canada's production of oil represents about 2 percent of the world total. Our production of natural gas is about 5 percent of the world total. Much of our coal is currently exported as is a considerable part of our supply of natural gas. Both these fuels contribute to production of electricity for use in Canada, though 2/3 of the electricity generated for use in Canada comes from Hydro. Canada currently has to import some oil and may have to continue to do so even with the development of frontier areas even if the use of oil continues to decline. Natural gas useage is expected to increase from its current level of 42 percent of the Canadian energy market to 45 percent by the year 2005. Wood, wood waste and pulping liquor are creditedd with making a significant future contribution to energy use in Canada(7%). The report indicates that 'minor contributions are expected in the later years of the projection period from municipal waste, active solar energy and peat'.

In view of the preceding summary, it is evident that the National Energy Board, for one, is not depending at all on future developments in the field of wind energy. The prevailing view in Energy Mines and Resources was expressed to me as an opinion that Wind Energy might contribute up to 1 percent of the total energy requirements of this country by the year 2000. This view is scarcely surprising considering the total lack of lobbying that goes on at the political level for wind energy developments. This view was also expressed in some documentation which I reviewed from the province of Ontario. In order to extricate us from this insoluble dilemma, I have decided to develop a test case for the Wind Industry in this country by a simulation process.

DEVELOPMENT OF A MAJOR WIND FARM SYSTEM TO CONTRIBUTE ELECTRICITY TO THE NATIONAL CAPITAL AREA FOCUSSED ON OTTAWA.

CHOICE OF LOCATION

The areas selected for WIND FARMING ARE The MADAWASKA HIGHLANDS AND THE ADJOINING MOUNT ST. PATRICK MOUNTAINS (These lie to the north and west of Ottawa within 100 miles of the capital.) There are numerous hydro developments in the intervening area which would help provide HYDRO corridors for delivery of electricity from the wind farm to the national capital. The area selected is largely uninhabited and at an elevation of over 1000 feet above sealevel.(Which provides exposure to winds approaching geostrophic wind velocity). There are already connecting roads developed within the area permitting truck access to the windfarm area but upgrading would be essential and new on-site feeder roads would have to be developed within the enterprise

For purposes of simulation, I intend to use the most recent production figures for electricity generated by the Wind Turbines Systems currently operating in California under contract to the two Public Electric Companies in the State.(3). I shall then compare their production at the present time to the current supply of electricity within the City of Ottawa.(4). The purpose of carrying out this marriage of data from two separate operations is to provide an answer to the following question.

IF CANADA HAD INVESTED THE TIME AND RESOURCES IN WIND ENERGY THAT HAVE BEEN EXPENDED BY THE STATE OF CALIFORNIA, WHAT WOULD HAVE BEEN THE IMPACT ON LOCAL SUPPLY OF ELECTRICITY DERIVED DIRECTLY FROM SUCH WIND FARM OPERATIONS ? —

The exercise yields the following results:

(A) ELECTRIC WIND POWER PRODUCTION IN CALIFORNIA
AS SOLD TO TWO STATE ELECTRIC COMPANIES 1985
(BASED ON JULY-AUGUST WIND TURBINE PRODUCTION
FIGURES FOR 1985) (3) - 192 MEGAWATTS

(B) AVERAGE TWO MONTH SUPPLY OF ELECTRIC POWER TO
OTTAWA DURING THE YEAR 1984 BY OTTAWA HYDRO (4)- 618 MEGAWATTS

(C) CALIFORNIA WIND FARM TWO MONTH PRODUCTION IN 1985
AS A PERCENT OF TWO MONTH ELECTRIC POWER PRODUCTION
BY OTTAWA HYDRO IN 1984 (A/B X 100) 31.1 PERCENT

The foregoing analysis is obviously based on very crude juxtaposition of data from two radically different environments. On the other hand there is little reason to feel that the wind production in California would be very much different from the production capabilities of the areas chosen for the wind farm in the Ontario countryside. I discussed the matter with Don Marier when I obtained the California figures from him. He did not feel that the results would be very biassed as judged from the information I passed to him by phone.

Th main messages coming to me from the foregoing analysis are that:

1) THERE IS A LEGITIMATE PLACE FOR A WIND INDUSTRY IN CANADA.
2) THERE IS A LONG TERM NEED TO DEVELOP SUCH FACILITIES BASED ON THE MOST ADVANCED TECHNOLOGY AVAILABLE INTERNATIONALLY.
3) GOVERNMENTS AND INDUSTRY IN CANADA OWE IT TO THEIR OWN SELF INTEREST TO PROVIDE FUNDING AND EXPERTISE TO ADVANCE THE WIND FARM INDUSTRY IN CANADA AS AN OPERATIONAL PARTNER IN THE GROWTH OF THE ENERGY RESOURCES NEEDED FOR CANADA'S CONTINUING GROWTH AS A POWERFUL MEMBER OF THE COMMUNITY OF NATIONS.

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IREQ's Aerogenerator Test Facility

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ABSTRACT

The aim of the aerogenerator testing facility at IREQ is to provide a broad reliable data base for validating simulation models currently under development at the Institute. The test program covers the dynamic characteristics of the wind turbine: the guy wires and the mechanical and electrical drive train under various loading conditions, both steady-state and transient. The machine presently used for these studies is a DAF INDAL 50-kw vertical-axis wind turbine modified to allow operation at variable speeds, with a three- or six-guy wire support at adjustable tension levels. The instrumentation, the electrical wiring and the data acquisition and processing system of the installation are described. The test program and typical test results (parametric resonance) are presented and discussed.

INTRODUCTION

A new test facility has recently been built at the Institute which can be used for studying both vertical- and horizontal-axis machines. The experience gained at the Magdalen Islands test site proved very useful when planning this facility.

DESCRIPTION OF SITE AND MACHINE

The Varennes site is well exposed to the prevailing westerly winds. The average annual wind speed is 4.7 m/s at a height of 10 m and the average hourly windspeed exceeds 5.5 m/s 36% of the time.

Installed in July 1983, the machine was manufactured by INDAL TECHNOLOGIES of Mississauga, Ontario, with a few modifications for the purpose of the tests (three or six guy wires, and variable-speed operation). The rotor is 17.5 m high, 11.2 m in diameter, and has two aluminum extruded blades with a NACA 0015 profile, and a chord of 0.36 m. Three different asynchronous electrical machines can be connected directly to the high-speed shaft:

1) one squirrel cage machine, whose stator is directly connected to the network transformer (nominal configuration);
2) one wound-rotor motor capable of driving the low-speed shaft up to 100 rpm (motoring mode only in zero wind conditions);

3) one wound-rotor machine, used in motoring and generating modes. This machine has a synchronous speed of 720 rpm and will absorb power from the low-speed shaft over the range from 47 to 95 rpm.

The two latter machines are connected to the network via a static-frequency converter and permit operation of the system at variable speed which is particularly useful for VAWT vibration and performance testing.

When the VAWT is in parked position, its low-speed gear rests on four braking shoes, while during operation, it and the rotor are lifted clear by means of a large hydraulic cylinder. The operating guy-wire tension can therefore be adjusted by suitably controlling the hydraulic pressure. This feature has an interesting advantage for test purposes in that, once the pressure is set, the guy wire tension will not be affected by temperature variations.

INSTRUMENTATION

The aerogenerator is presently instrumented with 48 sensors located as shown in figure 1. All instrumentation wiring and signal transmission lines and shields have been devised from the point of view of reducing electromagnetic pickup the sensor power supplies and outputs are fed via underground iron conduits to the signal-conditioning cabinet and to the A/D converter in the laboratory control room. All measurement and control cables are grounded via the same copper sheathing (figure 2).

DATA ACQUISITION AND PROCESSING

The data acquisition system actually in use has the following characteristics:

• Number of channels, N	1 to 24 ($N \neq 2$)
• Signal input level	± 10 V
• LSB A/D converter	4.88 mV
• Sampling rate, SR	4,760/N samp./s/chan.
• Test duration	15,360/(N·SR) s
• Samples per channel, n_p	15,360/N
• Min. frequency resolution, f with $n_e = (2k \quad n_p)$, k = 9, 10, 11	$2SR/n_e$ Hz

It is built around a microNova MP200. Test data is temporarily stored on the peripheral disk unit. The software developed for this test site has been described elsewhere (Flamand, 1984). Software programs for data display on a graphic terminal permit analysis in both the time and the frequency domains while hard copies can be produced on an Okidata printer, at the user's command. All test results are transferred to diskettes and sent to the main computer room where they are stored on tape for more detailed processing and analysis on IREQ's central computer.

For improving our knowledge on the phenomena occuring in the rotor in operation, a new signal conditioning and data acquisition system is presently being installed on the rotor itself. This system, developed at IREQ, will permit data collection from up to 48 analog signals (23 strain gauges, 1 torque cell and 24 accelerometers) at a maximum sampling rate of 375 Hz for each channel. Auto-calibration and zeroing of each sensor preamplifier on the rotor can be carried out by the user through simple software commands given from the laboratory terminal to the acquisition master unit in the rotor. The user can select sampling rate, number of channels to be recorded, sampling order through software commands as well. During data acquisition, the master unit on the rotor is responsible for synchronization of data acquisition among the six satellites, each of which is multiplexing data from 8 analog preamplified inputs. The satellites convert the data in digital form and sends it back to the master unit where it is stored. Up to 1 Mbytes can be stored in this unit during one test.

Once the test is completed, the stored digital data is transmitted serially to the lab computer through either a fiber optic rotating link (optical modem) or a pair of mechanical slip ring (DPSK modem), depending on the host terminal used in the lab (figure 3). Digital transmission offers major advantages over conventional analog transmission with mechanical slip ring which induces ohmic and/or cross talk noise, may cause significant attenuation in the case of long transmission lines and are generally limited in the number of signals they can economically handle.

The acquisition of signals on the rotating part is synchronized with that of the non rotating part insuring time coherence of all data gathered during any given test. The rotor data acquisition circuitry has been designed to operate in ambient temperatures ranging from -20 to +40°C and to withstand machine vibrations and centrifugal acceleration. Particular care was given to minimize electromagnetic noise pick up from any signals by using standardized shielding and grounding practices and having current preamplifiers located as close as possible to their sensors. Noise measurements of -61db (ratio of noise to reference currents) on a strain gauge preamplifier signal travelling from the rotor upper strut to the lab over a distance of 50 m has been measured experimentally in the field. The collected data will be processed and analyzed both in the time and frequency domain with the use of softwares developed at IREQ (VISA, Zmodal, TSFD). Modal identification with the two latter programs and the ITD software will be applied and the results used for the validation of simulation models currently in development on rotor dynamics.

TEST PROGRAM

The experimental program focuses on the static and dynamic behavior of the rotor, the support structure, the power train, the control system stability and the environment of a VAWT (Léonard, 1983). Figure 4 schematically describes the field of studies for which this test site was implemented.

EXPERIMENTAL RESULTS

As an example of the type of results collected, figure 4 illustrates a phenomenon known as parametric resonance, a situation which occurs when resonance of a structural member is induced by an excitation force having a frequency twice that of the resonance frequency. This example, recorded at a tip speed ratio of 4.25 and an average wind speed of 10 m/s shows the lateral vibration level recorded by an accelerometer located at mid-span of the guy wire, following an increase in the rpm reference setting. It is interesting to note the progressive change in the frequency content of the signal with time: the higher frequencies observed in the initial phase of the test gradually develop into a strong vibration, indicating first-mode resonance of the guy wire at a frequency of 1P excitation, even though the 2P aerodynamic excitation is dominant throughout the test, as indicated by the simultaneously recorded rpm and guy wire tension signals.

Other test results presented by Pastorel and Beaulieu (1985) have supported the validation of a simulation model of the nonlinear vibration modes of the guy wire support system.

Recently a series of tests have been completed on the vibration modes (in- and out-of-plane) of the rotor at rest. The results are presently being analyzed and will be used for completing the analytical model in development.

CONCLUSION

More than 400 documented tests are now on records since the aerogenerator was put in operation.

The expertise gained by IREQ's team in experimental testing of aerogenerators through this project has permitted to obtain high quality data on many transient phenomena and dynamic characteristics typical of the complex aerogenerator structure.

Throughout the test program we have obtained numerous results that, although often neglected in most windmill test centers, are of primary importance to the aerogenerator manufacturer. This facility has greatly improved our understanding of the complex interrelation of aerogenerator components and have significantly contributed in arriving at simulation models that are the most complete in describing the overall dynamics of the aerogenerator.

ACKNOWLEDGEMENT

The authors express their gratitude to the members of IREQ who have contributed to the success of this test facility. Thanks are due to François Léonard, Réal Reid, Henri Pastorel, Jacques Flamand, Louis Lamarche and Benoit Dubé for their sustained cooperation and advice throughout the course of the project.

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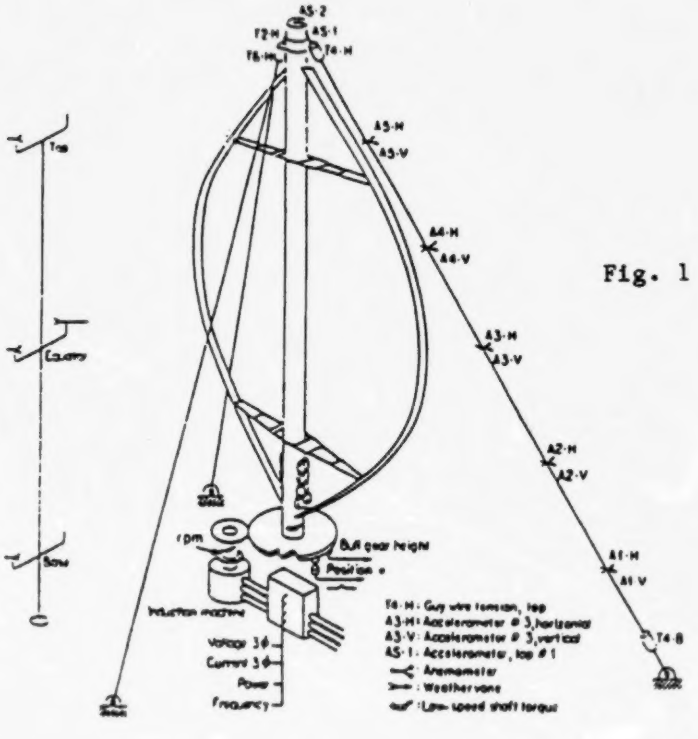
AS-2
T2-H
AS-1
T6-H
T4-H
A5-H
A5-V
A4-H
A4-V
A3-H
A3-V
A2-H
A2-V
A1-H
A1-V
T4-B
Top
Centre
Bow
rpm
Bull gear height
Position θ
Induction machine
Voltage 3ϕ
Current 3ϕ
Power
Frequency
T4-H : Guy wire tension, top
A3-H : Accelerometer # 3, horizontal
A3-V : Accelerometer # 3, vertical
AS-1 : Accelerometer, top # 1
: Anemometer
: Weathervane
: Low-speed shaft torque

Fig. 1 Instrumentation of the Darrieus wind turbine at IREQ

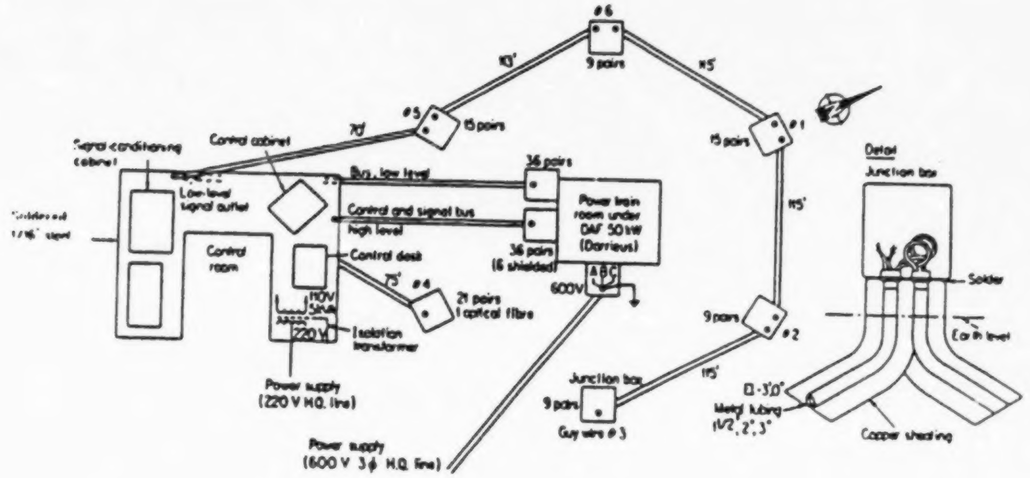
#6
9 pairs
110'
115'
#5
15 pairs
70'
#1
15 pairs
115'
Signal conditioning cabinet
Control cabinet
Low-level signal outlet
Bus, low level
36 pairs
Control and signal bus high level
36 pairs (6 shielded)
Power train room under DAF 50 kW (Darrieus)
Control room
Control desk
75'
#4
21 pairs 1 optical fibre
110V 5kVA
220V
Isolation transformer
600V
ABC
9 pairs
#2
115'
Junction box
9 pairs
Guy wire # 3
Power supply (220 V H.Q. line)
Power supply (600 V 3ϕ H.Q. line)
Detail
Junction box
Solder
Earth level
D-3'0"
Metal tubing 1 1/2", 2", 3"
Copper sheeting

Fig. 2 Instrumentation, control and power supply network

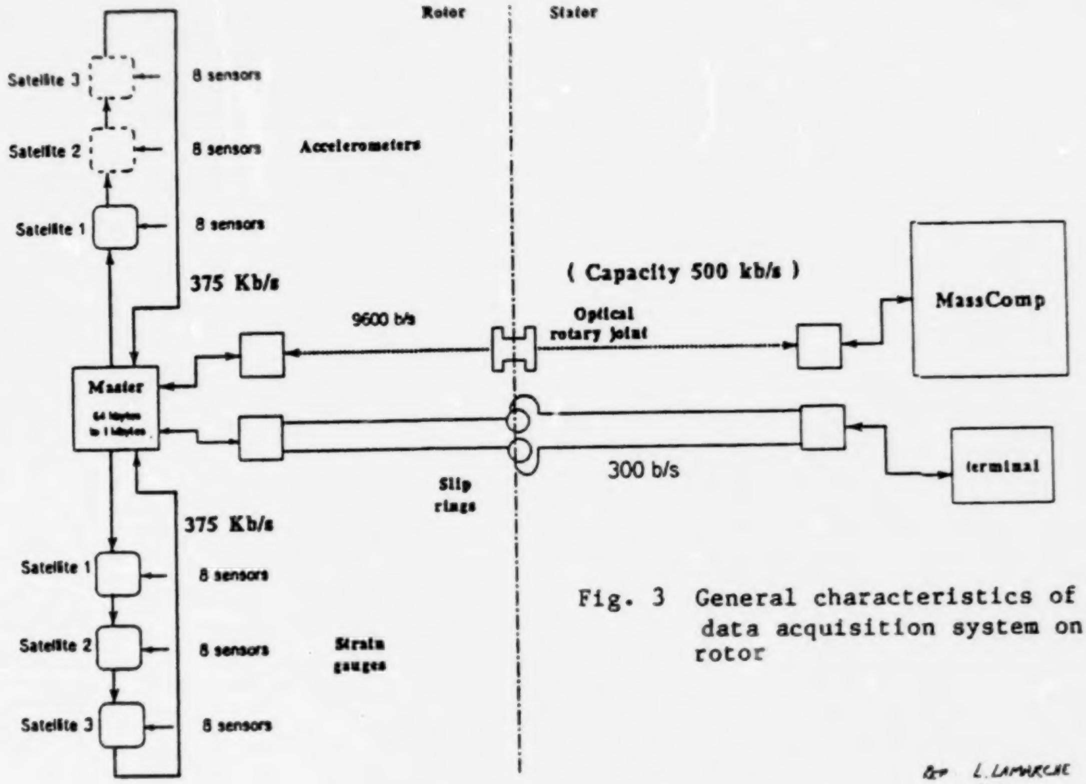
Rotor
Stator
Satellite 3
8 sensors
Satellite 2
8 sensors
Accelerometers
Satellite 1
8 sensors
375 Kb/s
(Capacity 500 kb/s)
9600 b/s
Optical
rotary joint
MassComp
Master
Slip
rings
300 b/s
terminal
375 Kb/s
Satellite 1
8 sensors
Satellite 2
8 sensors
Strain
gauges
Satellite 3
8 sensors

Fig. 3 General characteristics of the new data acquisition system on the rotor

L. LAMARCHE
IREQ

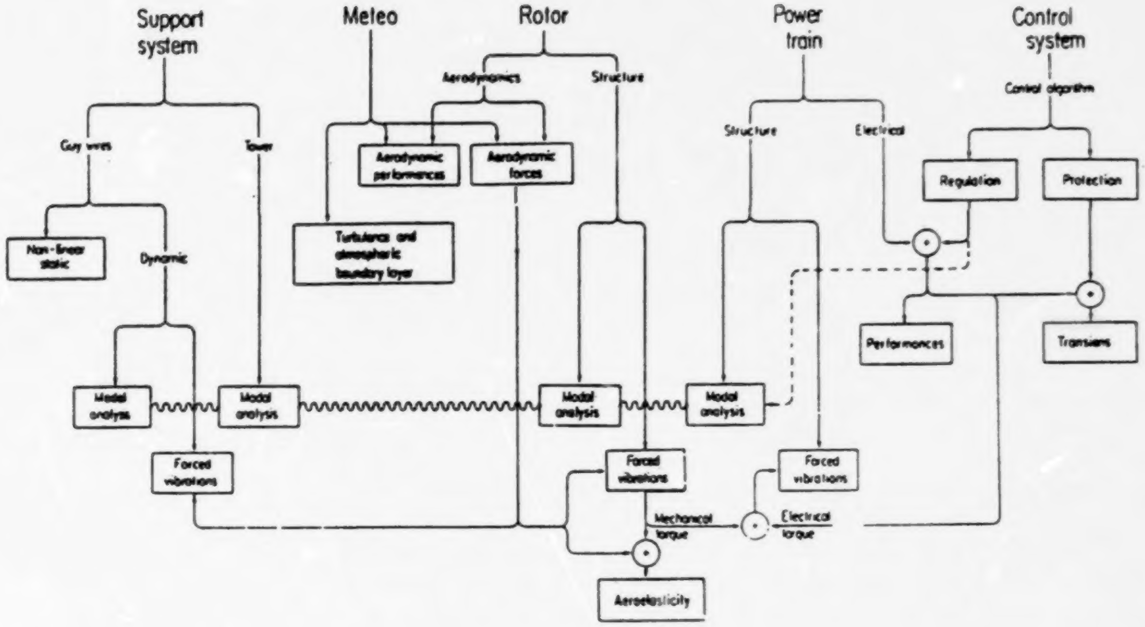
Support
system
Meteo
Rotor
Power
train
Control
system
Aerodynamics
Structure
Control algorithm
Guy wires
Tower
Aerodynamic
performances
Aerodynamic
forces
Structure
Electrical
Regulation
Protection
Non-linear
static
Dynamic
Turbulence and
atmospheric
boundary layer
Performances
Transiens
Modal
analysis
Modal
analysis
Modal
analysis
Modal
analysis
Forced
vibrations
Forced
vibrations
Forced
vibrations
Mechanical
torque
Electrical
torque
Aeroelasticity

Fig. 4 Flowchart of experimental test program

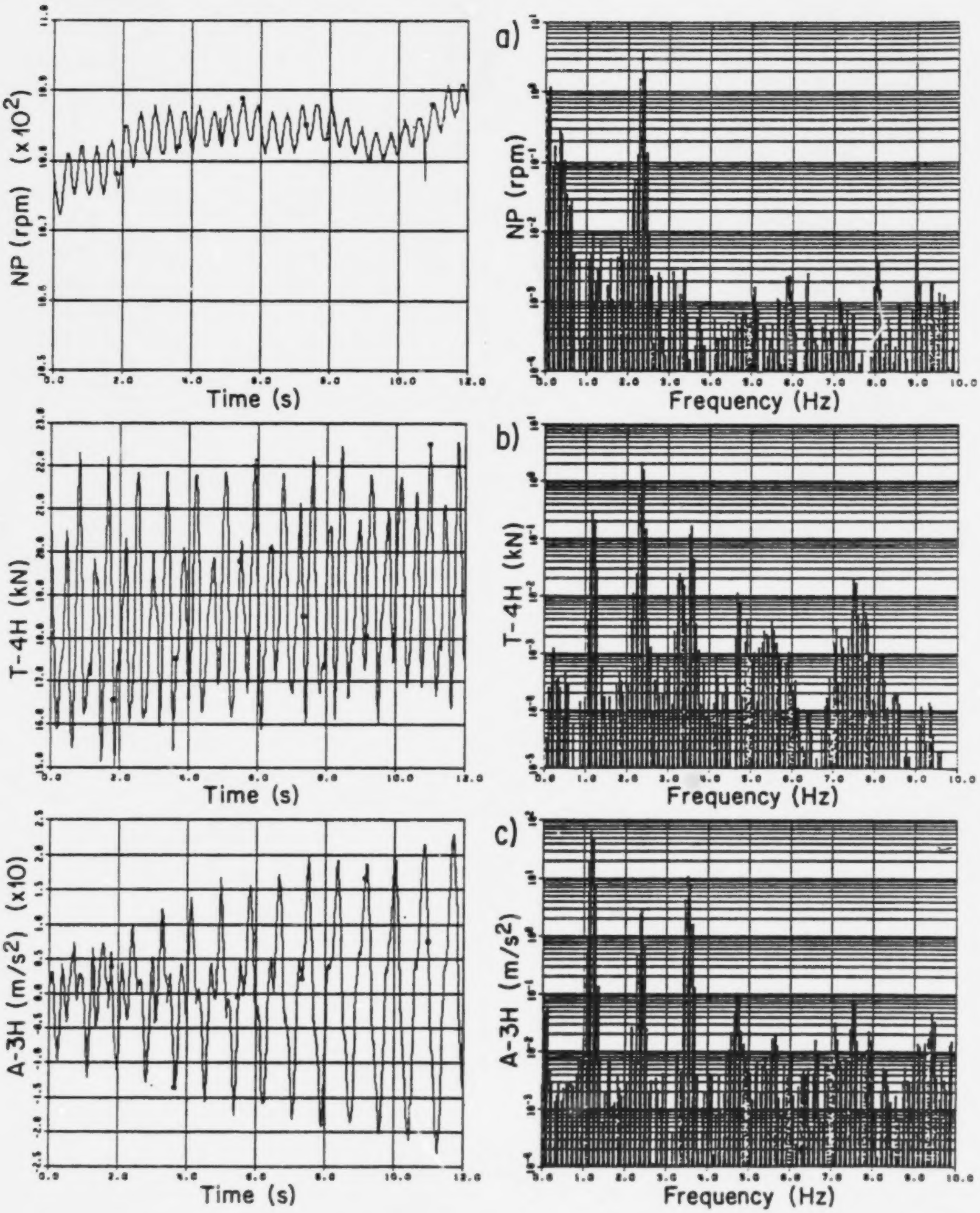

Fig. 5 Variations in parametric resonance with increasing rpm (vs time and frequency)
a) rpm
b) guy wire tension
c) horizontal-vibration level at mid-span of guy wire

RENEWABLE ENERGY POLICY/GOVERNMENT PROGRAMS

Canadian Wind Energy Association Conference

"WIND ENERGY R,D&D PROGRAM"

Monique Carpentier, P.Eng.

Wind Energy Technology Coordinator

Solar Energy Development Program

Energy, Mines and Resources Canada

Ottawa
December 9 & 10, 1985

In November of 1984, the Canadian Government issued [illegible] the Division of Energy of the National Research Council. As most of you already know, my department Energy, Mines and Resources as the federal agency now have the mandate to carry out Research, Development, and Demonstration (R,D&D) activities in the field of renewable energy, which includes wind energy.

I would like to present to you the main elements of the proposed Wind Energy R&D program, and its management structure. I would also like to give you the status of the demonstration programs such as the ENERDEMO and the Remote Community Demonstration Program.

In designing the R&D program it was recognized that no clear cut division exists between the Research and Development, and Demonstration activities but that a gradual evolution from one stage to the other is taking place. Now that the same division at EMR has the responsibility for directing the Research, Development and Demonstration it is our intention to maintain a certain flexibility to the programs in order to eliminate gaps between R&D and Demonstrations.

R&D PROGRAM:

The ultimate goal of the federal Wind Energy R&D Program is to encourage research to establish a technology base, and to support industry in confirming the viability of wind energy as an energy supply alternative.

But how are we going to achieve this goal?

MANAGEMENT STRUCTURE:

As a consequence of the manpower limitations and research expertise within RED/EMR, the management structure will utilize external expertise in the specific technologies by employing R and D Technical Advisory Committees (TAC's).

The intent, when inviting experts to serve on the TAC, is to obtain a broad representation from manufacturers of WECs, potential users of the technology, key individuals from research centres, and testing facilities, and individuals whose expertise complements that already represented in the other committee members.

David Malcolm from Indal Technologies Inc. was selected at the CanWEA annual meeting (Dec. 8th) as the Industry representative and Saeed Qurashi as his substitute.

One of the primary functions of the TAC is to provide advice regarding R and D priorities in a specific technology and to assist EMR in directing the R&D program.

PRIORITY AREAS R&D

After extensive consultations with the industry, research institutions, government agencies and users, several areas of the wind energy technology were identified as priority areas for R&D activities. These priority areas are largely tied to the development of cost-effective and reliable wind turbines that will be needed to respond to the near and long term Canadian market development. I must admit this selection was also influenced by the level of funding available.

Six priority areas were identified:

	(approx. funding) ($000/year)
- Generic Research	150
- Technology Development	200
- Wind/Diesel System Development	300
- Technology Testing and Monitoring	380
- Wind farms/arrays	150
- Technology transfer	50
	1230

For each area, goals and objectives are established as well as specific targets when appropriate.

Basic Research:

The first step towards designing more cost-effective wind machines is to develop a good understanding of the basic physical processes created by the turbine's interaction with its environment. For example, computer models to accurately predict the aerodymanic performance, the energy yield under different conditions and the structural dynamic behavior of a windmill rotor already exist in one form or another. However, these models are of no value if they cannot be accessed or used by wind manufacturers. The objective in this area is to provide tools that will allow industry to design and develop more cost-effective and reliable wind machines and wind energy systems.

An approximate funding of $150,000/year is projected.

Technology Development:

Several Canadian companies can now identify themselves as WECS manufacturers. However, the Canadian WECS are not all at the same stage of development. Some are at the research stage, some are at the development stage and others on the verge of commercialization, but all of them could be improved in some way.

The goal of the product technology development activities is to achieve improvements in machine costs, performance, reliability and lifetime. The status and goals are summarized in the following table:

WIND ENERGY TECHNOLOGY * STATUS AND GOALS

	CURRENT	FUTURE	
		NEAR TERM	LONG TERM
CAPITAL COST (INSTALLED)			
Windfarms, (convenient sites)	\$500/m^2 to \$1,000/m^2	\$300/m^2 to \$400/m^2	
Remote, northern, single units	\$1,000/m^2 to \$3,000/m^2	\$600/m^2 to \$1,200/m^2	
Waters pumpers (6m lift)	4¢ to 6¢/m^3	3¢ to 4¢/m^3	2¢/m^3
RELIABILITY (after 1 year operation of prototype)			
Availability	85%	90%	95%
Mean Time Between Failures	Months	about a year	years
MAINTENANCE COSTS	high	better	1/2¢ to 1¢/kWh

You see on the graph that no specific year is given for the near term and long term goals. It is a little bit difficult to establish these dates now, considering the changes in R&D funding and responsibilities, but one thing is for certain, we have to make progress over the year. To achieve these goals, research is required in the basic science of wind turbine dynamics, advanced components and system development. Such generic research will provide the tools to help identify, test and evaluate new concepts. Those tools made available to the industry or developed by the industry will facilitate the design and development of more cost-effective wind machines and as research and scientific knowledge progress, innovative concepts to improve wind technology are likely to emerge.

A funding level of 200K/year to 400K/year is suggested, this type of activity can be co-funded by other government programs.

Wind/Diesel Systems:

Today, the major Canadian domestic wind energy market is in the remote areas. Fuel costs for electricity from diesel-generator system range from about 8 ¢/kWh to about 75¢/kWh and in some instances exceed $1.00/kWh. Many of these sites have moderate to good wind regimes. If WECS are to establish technical and economic credibility in remote areas, considerable attention must be paid to detailed systems engineering for these applications.

Incorporating wind energy into traditional community-scale diesel powerplants involves several technical challenges, most of which are related to control system design and overall systems engineering. Both load and wind energy vary randomly with time; thus, diesel controls may have to maintain stability for the entire system. Means must be provided to absorb surplus power when wind power exceeds instantaneous load less the minimum permissable load on the diesels. Automatic dispatching of sets within a power-house must be carefully prescribed to avoid multiple starts, prolonged running at low loads, and momentary overloads, while maintaining reliable, high-quality supply to the community.

To achieve reliability and economic credibility in wind/diesel systems for remote areas. We proposed an annual budget of 300K.

Technology Testing and Monitoring:

The continued operation and testing of developing and existing machines was recognized by the wind community as critical to achieving further advances in wind technology. Fortunately, well-equipped, test facilities staffed with experienced personnel for use by WECS manufacturers and WECS users exist in Canada. The Lethbridge Waterpumping Test Site in Alberta and the Atlantic Wind Test Site (AWTS) located at Prince Edward Island are good examples.

To make the expertise from testing sites available to the wind community, it will involve supporting cooperative efforts between government and industry to test WECS at a test site before their deployment, as well as monitoring demonstration units on site.

An annual budget of 330K will be available for these activities, of which a very substantial amount is coming from NRC as a direct subsidy to the AWTS.

Wind Farms/Arrays:

A second market in Canada in the longer term may be windfarm applications. A current capacity surplus for most utilities as well as other institutional barriers mitigate against rapid development of large and numerous wind farms in Canada. However, good wind regimes plus relatively expensive conventional energy production costs may make some parts of Canada fertile areas for multi-unit arrays of intermediate-scale WECS. Iles de la Madeleine, with over 50MW of diesel-generators and an annual average wind speed of nearly 10 m/s, presents an ideal wind energy site. Similar opportunities exist on the Queen Charlotte islands in British Columbia, in Prince Edward Island, and in Newfoundland. It is very likely that the first Canadian wind farms will be demonstrated in FY 86/87 in one of these regions. Although many wind farms already exist in the United States, more research and development remains to be done especially in developing efficient array controls, in studying interactions between units and grid, etc. Considering the limited funding, approximately 150K for the R&D activities, it will be important to not duplicate the research already done by the United States.

Technology Transfer:

Technology transfer is an essential activity to establish wind technology as a viable energy option. To be effective, it must be an integral part of all activities in the program. Technology transfer can be achieved through several vehicles:

- Regular communication with industry and other groups;
- conferences;
- publications related to program activities;
- special technical workshops;
- research results publications;
- liaison with national associations.

For example Canadian Wind Energy Association through its Annual Wind Energy Conference and Bulletin appears to be one excellent vehicle for the dissemination of information.

Technology transfer activities will be evaluated and implemented throughout the program. An annual budget of 50K is considered.

For those of you, who took note of the proposed funding level for each year in each of the priority areas, and if you add them up, the total is higher than the 750K year which is always mentionned as being the wind energy R&D budget. My numbers take into account other sources of funding which was not uniquely related to R&D or coming from other Departments.

I would also like to mention that a certain flexibility will be maintained within all the technology programs. If you propose very good R&D projects I am fairly confident that we will be able to find the money to assist you in carrying them out.

These are the priority areas for the Wind Energy R&D Program. A general request for proposals will also soon be issued covering wind and other renewable energy technologies. Copies of this RFP are available during this conference for anyone of you who may be interested in an advanced copy. Proposals must be received by January 31st and review is scheduled for February. It is anticipated that contracts will be in place by March or April.

Demonstration Program:

A program of interest to the wind energy community is the Remote Community Demonstration Program (RCDP) which was introduced in 1980. RCDP is designed to encourage communities not connected to the main electrical grid or natural gas supply system, to investigate their off-oil opportunities and then to fund selected demonstration projects. Under Phase I, nine pre-feasibility studies related to wind energy have been done. The following graph provides a list of these studies and their corresponding funding levels. One project in Ontario has already been approved under Phase II of the program. The demonstration of a wind/diesel system will take place in Fort-Severn, Ontario. The project is managed by Ontario Hydro and contributions are provided by the Ontario Ministry of Energy, Howden Group Canada, Ontario-Hydro and Energy, Mines and Resources Canada. Wind Energy project demonstrations have been recognized as priority for the provinces of Québec, Newfoundland and the Northwest Territories.

REMOTE COMMUNITY DEMONSTRATION PROGRAM

(RCDP)

PHASE I

PROVINCE	LOCATION	DISCRIPTION	RCDP FUNDING ($000)	TOTAL ($000)
NORTHWEST TERRITORIES		WIND/HYDRO HYBRID	60	60
BRITISH COLUMBIA	KITKATLA	WIND FEASIBILITY	22	27.5
QUEBEC	ISLES DE LA MADELEINE	WINDFARM (WIND MEASUREMENT)	36	48
		SMALL WINDMILLS	50.4	50.4
ONTARIO	MUD RIVER	WIND FEASIBILITY	3	3
NEWFOUNDLAND	SOUTH COAST	WIND FEASIBILITY	53	53
	LABRADOR COAST	WIND FEASIBILITY	14	14
	ST. ANTHONY	WIND FEASIBILITY	21	25.3
	PINSENTS ARM/ NORMAN BAY	PV/WIND CYCLE CHARGE	30.6	30.6

The second demonstration program is Enerdemo-Canada. It is designed to demonstrate the value of new technology in renewable and energy conservation applications for all sectors of the economy. The following table provided the number of projects submitted and approved in the renewble energy sector only. One wind project was approved, the project is proposed by Delta Windpump Corporation to install a 65" diameter water pumping windmill to produce marshland. The windmill will be the property of Ducks Unlimited. The concerned parties are now processing the Agreement. Only one wind project has been approved up to now under Enerdemo-Canada but this is only a beginning.

ENERDEMO:

ENERDEMO HIGHLIGHTS

SECTOR	PROJECTS
PHOTOVOLTAICS	2
SMALL SCALE HYDRO	2
SOLAR	3
WIND	1
HEAT PUMP	2

PROJECTS APPROVED	10
PROJECTS SUBMITTED	24
TOTAL PROJECTS COST	$1.7M
EMR CONTRIBUTION	$0.5M

This concludes my presentation, the proposed R&D program was presented to you as well as to the two principal demonstration programs.

THE ECONOMICS OF AND MARKET POTENTIAL FOR WIND ENERGY SYSTEMS IN CANADA

Jay Barclay
Jane Oliver
Renewable Energy Division
Energy, Mines & Resources Canada
December 1985

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1. INTRODUCTION

Over the past few years, R&D efforts in the wind energy area have led to the emergence of a Canadian manufacturing capability. This development has been partly fueled by significant growth in the worldwide market for wind machines, particularly in California. The development of a Canadian industrial capability has naturally led to an increasing interest in domestic market applications for wind energy systems.

The increased interest in wind energy has encouraged Energy, Mines and Resources to more carefully examine the economics of and market potential for wind energy in Canada. This paper reports on the results of our ongoing analysis work. It focusses on two potential wind energy applications for medium scale machines in both remote community and grid applications, and discusses the market potential in Canada.

2. APPLICATIONS

There are two basic designs for wind turbines: horizontal axis (HAWT) and vertical axis (VAWT). The VAWT has its controls and machinery on the ground whereas the HAWT has this equipment at hub height. Although the design is different, both types are equally well suited to any application. The most common application of wind turbines is electrical generation although the use of these turbines for water pumping is also common.

General size classifications are useful in delineating applications. Very small systems (0-10kW) are used for navigational aids or decentralized private use. Private use applications include electrical generation as well as water pumping. Small-scale systems (10-100 kW) may be used for private use but are more suited to remote community applications (wind/diesel hybrids), wind farms or commercial use. Medium scale turbines (100-500 kW) are best suited in remote community applications or wind farms. Larger systems (500 kW up to 4 MW, to date) are most likely to be used to meet utility demand.

In Canada, at present, wind turbines are producing electricity for navigational use, remote community supply as well as for water pumping applications. While none exist in Canada to date, there are proposals for the development of wind farms.

3. ECONOMIC ANALYSIS

Introduction

This section discusses the current relative economics of two wind energy system applications: a wind/diesel hybrid for remote communities and a wind farm for larger scale remote applications and for grid supply. The current cost of wind generated electricity is calculated for a number of different turbines and wind speeds which permits a close examination of some of the factors affecting wind energy viability. A reasonable range of turbine sizes, manufacturers and wind speeds is considered in order to achieve a general overview of the present economics of wind energy.

Methodology and Cost and Data Assumptions

The methodology used in this analysis is life cycle costing. This method considers costs (equipment purchase, installation, O&M, fuel) that are incurred over the life of the system, and the life cycle cost is calculated as the present value sum of these costs over the expected life of the equipment. To determine a per unit cost, the present value of costs can be divided by the present value sum of the energy produced to obtain a supply price. The supply price is also referred to as a levelized unit production cost. This approach weights costs over a project lifetime through a discount rate that reflects the value of time. It yields a single number that permits a valid comparison with other technologies with the same plant life. In this report a supply price comparison is used to evaluate wind and other electricity generation systems. With this methodology, a wind system is judged to be cost effective if its supply price is less than the supply price of the conventional alternative. The supply price approach can also be used to estimate the break-even cost for wind systems.

The supply price methodology is used to determine the cost of diesel generated electricity with the inclusion of fuel costs. For the diesel alternative in remote communities, it is assumed that the diesel system is already in place and, therefore, only operating and fuel costs are considered in the calculation.

The cost of off-road diesel fuel is dependent upon location but generally remote communities pay a higher price than urban areas due to higher transportation costs. Delivered costs vary from about 30c/l up to 77c/l. For the base case analysis, a price of 50c/l was chosen because it is representative of a large number of community prices. A sensitivity range of 30 and 75c/l is used.

Operation and maintenance costs for diesel generator are usually cited in cents per kilowatt-hour. In the report "Energy Overview Study for Remote Communities in British Columbia," it is stated that most of its communities have an average O&M cost of 1.8c/kWh of total energy production. This rate was assumed in this paper. The sensitivity analysis considered a range of 1 and 3c/kWh.

The conversion rate refers to the amount of electricity that can be generated from one litre of diesel fuel. Conversion rates usually range from 1.3 kW/l to about 3 kWh/l. Most systems average around 2 kWh/l and Ontario Hydro has used this estimate in their studies. This rate will be used in this study with a sensitivity range of 1.5 and 3.0 kWh/l.

A forecast of diesel prices was also required to determine the supply price. EMR has prepared a high and a low oil price forecast. For the purpose of this report, EMR's high oil price forecast scenario was used to index diesel fuel prices. This scenario assumes that diesel fuel prices increase an average of two percent real a year for the period 1983 to 2000.

Using an average diesel efficiency rate of 2 kWh/l and the diesel fuel mentioned above, the supply price of diesel generated electricity was found to range from 19.87c/kWh to 50c/kWh.

For utility generated electricity, the cost estimates used in this report are based on information provided in a 1980 report by the Special Studies Branch of EMR entitled "Energy Reference Cost Premiums." The cost estimates have been adjusted to represent 1983 costs, and are used to evaluate the relative economics of wind generated electricity in grid applications. The reference cost premiums are estimates of the divergence between market prices and social costs. They do not include environmental costs but are intended to reflect the system expansion cost to electrical utilities. These premiums are added to market prices at the project site to arrive at an estimate of the long run marginal supply price or reference cost.

In addition, for some provinces, the short run marginal costs of utility electricity supply are estimated to determine the attractiveness of wind energy systems as fuel savers. These data are obtained from an EMR Office of Energy Research and Development (OERD) report entitled, "Analysis of Near Term Costs of Wind Generated Electricity." The marginal operating costs reflect the short-run cost of producing one more unit of energy, and include fuel costs as well as operation and maintenance costs.

Table 1 presents the reference costs (long run marginal supply price including the cost of expansion) of utility generation. These costs range from 4.44c/kWh to 7.54c/kWh. Ontario has relatively low expansion costs primarily due to the assumed cost of nuclear capacity. Quebec has low costs due to its abundant and comparatively cheap hydro supply. The short run marginal cost of generation for each of the Maritime provinces and for Newfoundland is also shown in Table 1. These costs range from 3.26c/kWh to 10.4c/kWh.

A number of analytic assumptions are made in this paper as outlined below. A sensitivity analysis on each variable is performed to indicate which factors impact most significantly on the viability of wind energy.

Parameter	Base Case	Sensitivity
Discount Rate	7%	4, 10
System Life	20 yr.	10, 30
O&M Costs	2.5% Total Cost	1, 5

Table 1

Utility Electricity Costs

(1983¢/kWh)

Province	Predominant Energy Source	Long Run(1) Marginal Supply Price	Fuel to be Displaced	Short Run(2) Marginal Cost of Generation
Newfoundland	Hydro	6.41	Coal & Oil	3.30
Nova Scotia	Coal	7.54	Coal	4.00
P.E.I.	Oil	7.54	Oil	8.00
New Brunswick	Coal	7.54	Oil	5.047
Quebec	Hydro	4.44	N/A	N/A
Ontario	Nuclear	4.44	N/A	N/A
Manitoba	Hydro	6.51	N/A	N/A
Saskatchewan	Coal	5.83	N/A	N/A
Alberta	Coal	5.45	N/A	N/A
British Columbia	Hydro	5.96	N/A	N/A

Source: (1) "Energy Reference Cost Premiums (Draft)", Special Studies Branch, EMR, June 1980.

Data updated to 1983 assuming methodology described in this paper and a CPI of 2,098 in 1980 and 2,808 in 1983.

(2) "Analysis of the Near Term Cost of Wind Generated Electricity," Office of Energy Research and Development, EMR, April 1984.

* The short run marginal cost of generation for Nova Scotia Power was not available. The primary fuel source is coal and the average New Brunswick coal generation price was assumed to approximate the generating cost in Nova Scotia.

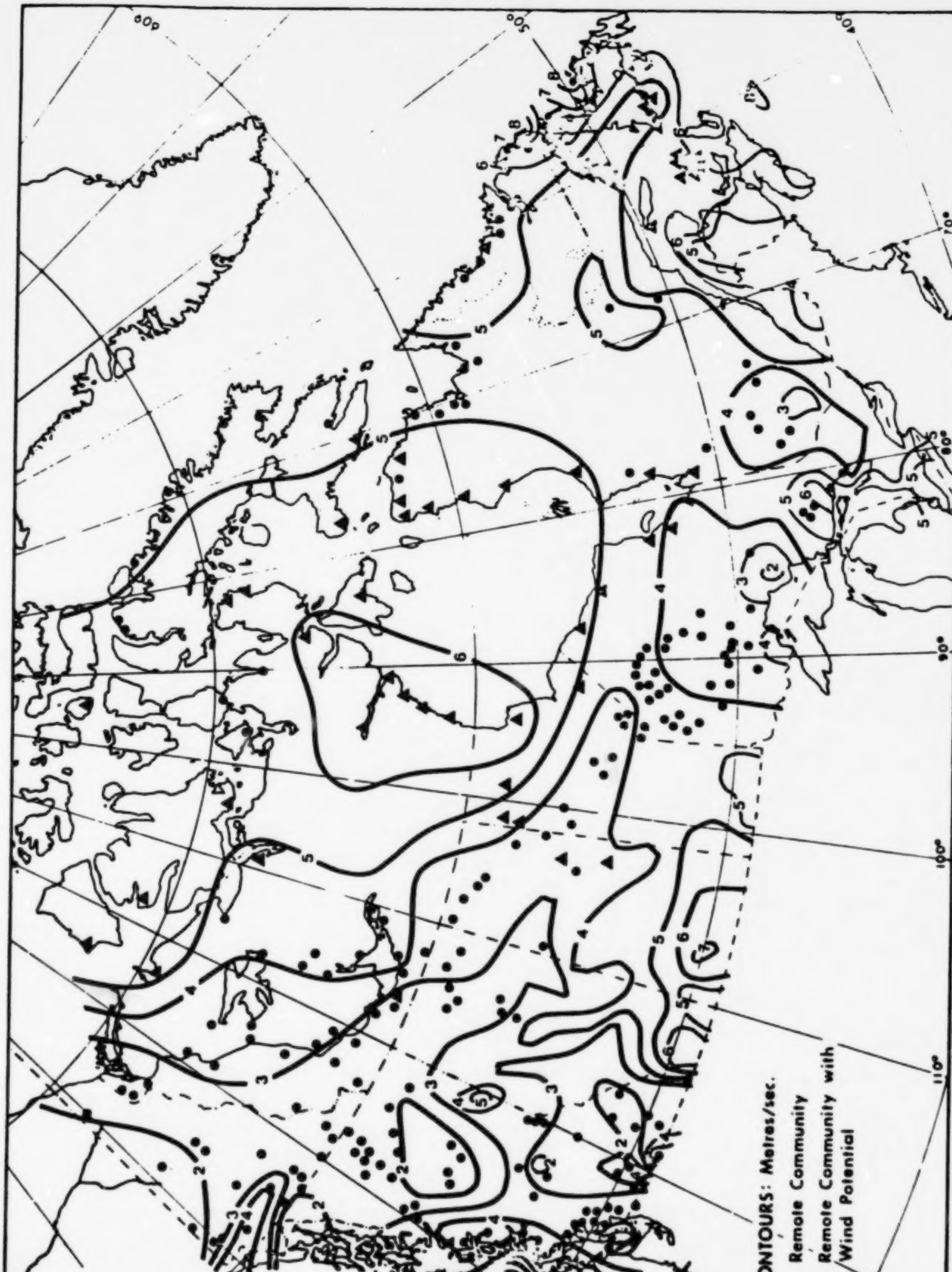
Wind System Data

The expected annual energy output of the wind turbines was estimated using a computer program developed by Energy, Mines and Resources. The program estimates the number of kilowatt-hours per year generated by various turbines under different scenarios. A probability distribution curve of wind speeds and the output performance curve for each wind turbine are required input data. The energy produced at each wind speed is summed to give the total annual electrical production of each wind turbine. A number of assumptions are required for this program. The basic assumptions are a Weibull coefficient equals two, availability of 100 percent, a wind shear coefficient of zero and an average hub height of 10 metres. The base case wind speed is 6.26 m/s with a sensitivity range of 4.47 m/s to 9.0 m/s. Wind speeds of this range can be found in Canada as shown on the following map.

Total installed costs per rated capacity range from $910 to $5,200 with an average of $2,500. The capital cost per rated capacity ranges from $1,250 to $3,200 for small and medium scale systems, and $682 to $5,575 for large scale systems. The turbine cost per unit for all turbines except the Adecon and the WTG represent the price the turbine would have cost in 1983. The cost for the WTG turbine includes a discount for volume purchase. Finally, the cost of the Adecon wind farm is a cost estimate for a future installation. This cost level has not yet been achieved.

The total installed costs of wind turbines include the capital cost of the turbine and the installation costs including transportation, site preparation and erection. It is assumed that the turbine is installed at the community site or near utility transmission lines such that transmission costs are insignificant. The capital cost data for each turbine are obtained from the manufacturer's. This study analysis uses an average estimate of the incremental costs of transportating a wind system to a specific location. However, it should be noted that actual installation costs can vary greatly and can significantly increase the total installed cost, particularly for remote communities. Table 2 presents the total installed cost per rated output for all turbines along with the energy output at three average wind speeds.

FIGURE 1


CONTOURS: Metres/sec.
● Remote Community
▲ Remote Community with Wind Potential
2
3
4
5
6
7
8
10
60°
50°
40°
70°
80°
90°
100°
110°
120°

MAP 1 - MEAN VELOCITY WIND CONTOURS, DECEMBER - APRIL

Table 2
Performance Characteristics of Wind Turbines

Turbine (Scale (kW))		Total Installed Cost (1983$/kW)	Electricity Production (kWh/year) and Plant Factor (%) at Average Wind Speed (m/s) of:					
			4.47 m/s (kWh/year)*	(%)	6.26 m/s (kWh/year)*	(%)	8.05 m/s (kWh/year)*	(%)
Jacobs	10	4,000	10,520	12.0	24,440	27.9	38,340	43.8
Carter	25	2,800	13,590	6.2	41,070	18.8	76,250	34.8
DAF Indal	50	5,200	19,590	4.5	67,530	15.4	123,580	28.2
Polenko	60	2,666	60,970	11.6	143,870	27.4	226,290	43.0
Wind Master	150	2,600	75,000	5.7	242,150	18.4	438,870	33.4
WTG	200	2,500	147,760	8.4	423,330	24.2	769,200	44.2
Carter	200	2,500	91,870	5.2	268,380	15.3	511,370	29.2
DAF Indal	500	1,860	92,620	2.1	373,760	8.5	805,090	18.4
Adecon Farm [a]	1000	910	673,600	7.7	1,762,480	20.1	2,654,240	30.3
MOD2	2500	2,448	1,477,570	6.7	4,727,610	21.6	8,096,510	37.0
WTS4	4000	2,385	638,110	0.2	3,259,460	0.9	7,438,920	2.1

*Annual production figures are based on mean annual windspeeds and a Weibull probability distribution with k=2.

[a] Wind farm of eight Adecon 125 KW wind turbines.

Supply Price Analysis - Small and Medium Scale Turbines Versus Diesel

The supply prices of the small and medium scale wind turbines examined in this paper are presented in Table 3. The prices range from 7.76c/kWh at high wind speeds (8.05 m/s) to 65c/kWh at the lowest wind speed (4.47 m/s). By comparison, the supply price of diesel generated electricity ranges from 19.6c/kWh to 49.26c/kWh (based on a 30-80c/l diesel fuel price range).

The results indicate that at lower wind speeds (less than 5 m/s or 11.2 mph), diesel costs must generally be in excess of 60c/l for wind energy to be an attractive option. The Polenko 60 kW and WTG200 kW turbines are competitive with 30c/l diesel fuel at wind speeds of 5.6 m/s (12.5 mph) and greater. The DAF Indal 50 kW turbine remains unattractive even compared to 80c/l diesel prices, at wind speeds less than 6.15 m/s (13.75 mph). At the average cost of diesel fuel for remote communities (50c/l), most of the wind turbines analysed are cost competitive at wind speeds of 5.6 m/s (12 mph) or greater.

The break even cost analysis supports this conclusion. With wind speeds of 5.6 m/s (12.5 mph) and a diesel cost of 50c/l, the break even costs range from $1300/kW to $5300/kW, encompassing the cost range for the majority of turbines. For lower wind speeds (4.47 m/s or 10 mph), most of the turbines have break even costs in the $1000/kW to $1500/kW range.

Wind energy is cost competitive for remote communities with relatively low diesel fuel costs, (30c/l) only if average wind speeds reach 6.5 m/s (14.5 mph). Total installed costs would have to be $1800/kW for remote communities facing 30c/l diesel costs and 5.6 m/s (12.5 mph) average wind speeds for wind generated electricity to be economically attractive.

Table 3

Supply Prices of Small and Medium Scale Wind turbines

(1983 ¢/kWh)

Wind System (Total Installed Cost)	Average Annual Wind Speed in m/s 4.47	5.00	5.59	5.80	6.26	6.51	7.00	8.05
Jacobs 10kW $40,000	45.40	34.70	26.00	23.13	19.54	18.03	16.00	12.46
Carter 25 kW $70,000	61.50	41.27	28.56	26.00	20.35	18.25	15.67	10.97
DAF Indal 50kW $260,000	158.46	93.60	65.75	58.16	45.97	40.56	34.03	25.12
Polenko 60kW $160,000	31.33	22.84	16.48	15.74	13.28	12.00	10.64	8.44
WindMaster 150 kW $390,000	62.08	40.04	27.30	24.13	19.22	17.82	14.31	10.55
WTG Energy 200 kW $500,000	40.40	27.70	19.53	17.50	14.10	12.50	10.57	7.76
Carter 200 kW $500,000	64.98	44.44	31.14	27.50	22.24	19.92	16.39	11.67
DAF Indal 500 kW $930,000	119.88	71.28	45.02	39.11	29.71	26.00	20.59	13.79

Supply Price Analysis - Medium Scale Wind Turbines Versus Utility Electricity

The supply price of wind energy systems varies considerably depending upon system costs and wind speed as illustrated in Table 4. The analysis indicates that the most cost effective wind turbine is the Adecon 125 kW machine, with a supply price of 6.16c/kWh at a 6.26 m/s (14 mph) average annual wind speed. This supply price compares favourably to the estimated long run marginal supply price of utility generated electricity in the Atlantic provinces (6.4 - 7.5c/kWh). With average annual wind speeds of about 6.5 m/s (14.5 mph) in many locations throughout Atlantic Canada, wind energy could be cost competitive at costs of about $1000/kW. A comparison of long-run marginal supply prices for utility-generated electricity to the supply price of wind generated electricity indicates that other wind systems become cost competitive at wind speeds of about 7 m/s or greater.

A break even analysis was also performed using three different utility reference costs (3.42c/kWh, 5.05c/kWh and 10.4c/kWh). The average reference cost for utility produced energy across Canada is about 5.05c/kWh. An analysis utilizing this figure and assuming a relatively high wind speed of 8.05 m/s indicates that the WTG wind farm, the Adecon windfarm, the MOD2, and the WTS4 must achieve installed cost levels of $1627/kW, $1,123/kW, $1370/kW and $787/kW, respectively, to be competitive with conventional electricity. It is possible the Adecon wind machine has already achieved this cost level. At an electricity cost of 10.4c/kWh, the WTG wind farm, consisting of five WTG 200 kW machines, is cost-effective at wind speeds over 6.7 m/s and the MOD2 is competitive at average wind speeds of 8.05 m/s (18 mph). At this cost level, the Adecon wind farm is cost-effective at a much lower wind speed of 5.2 m/s.

Given a utility cost of 3.42c/kWh, the break even cost of the 5 x 200 WTG wind farm is $1100/kW at a 8.05 m/s (18 mph) wind speed. In comparison, the installed cost of the Adecon farm must fall to $760/kW in order to break even at this wind speed and electricity value. The WTS4 has a break even cost of $533/kW at a wind speed of 8.05 m/s. It is unlikely this price reduction cost will be achieved in the near future--if at all.

Table 4

Supply Prices of Megawatt Scale Turbines and Wind farms

(1983 ¢/kWh)

Wind System	Average Annual Wind Speed in m/s						
(Total Installed Cost)	4.47	5.00	5.59	6.26	6.51	7.00	8.05
MOD2 2.5 MW 2nd Unit $6,120,000	49.45	33.50	21.49	15.46	13.97	11.78	9.02
MOD2 2.5 MW 100th unit $3,260,000	26.15	18.00	11.30	8.11	7.33	6.18	4.73
WTS4 4 MW 2nd Unit $9,540,290	178.50	99.16	56.08	34.95	30.13	23.36	15.31
WTS4 4 MW 100th unit $2,489,000	35.58	20.01	12.17	7.85	6.85	5.40	3.65
Wind farm 5 x 200kW WTG $2,250,000	36.36	24.93	17.57	12.69	12.00	9.50	6.98
Adecon farm 8 x 125 kW $909,747	16.12	11.13	8.09	6.16	5.70	4.97	4.09

Wind turbines not only provide capacity but may also be used as fuel savers. When the wind is blowing, electricity would be drawn from the turbines and consumption from conventional generators will decrease, thereby saving fuel. At an average annual wind speed of 6.5 m/s (14.5 mph) the total installed cost of the MOD2, WTS4, WTG windfarm and the Adecon windfarm must fall by 64, 83, 56 and 11 percent, respectively, to be competitive with electricity priced at 5.05c/kWh.

Sensitivity Analysis of Wind Energy Supply Price

The preceding results are contingent upon the assumptions. The importance of these assumptions can be tested by changing one assumption at a time and comparing the results to the base case.

The wind system chosen for the sensitivity analysis is the Polenko 60 kW turbine. Although only one wind system was examined, the sensitivity results are applicable to the other turbines, except the effect of wind speed on the supply price. Due to the specific performance characterisitics of each turbine, this effect cannot be generalized.

The base case supply price for the Polenko machine at a 6.26 m/s (14.5 mph) wind speed is 13.38c/kWh. The sensitivity analysis indicates that the most important factors affecting the economic viability of wind energy are wind speed, wind shear, total installed cost and the time frame. Wind speed has the most significant effect on the supply price. The results indicate that the supply price increases 2.7 times (to 31.3c/kWh) for a 28.6 percent reduction in wind speed (from 6.26 to 4.47 m/s). With a corresponding increase in wind speed (to 8.05 m/s), the supply price falls 36.4 percent (to 8.4c/kWh). A change in the total installed cost of a wind energy system has a directly proportional effect upon the supply price. A 100 percent increase in O&M costs causes the supply price to increase by 17 percent. Reducing the time period of analysis to ten years increases the supply price by 40 percent. Altering the discount rate does not result in a significant change to the base case results.

Sensitivity of Diesel Generated Electricity Supplv Price

The sensitivity analysis for the diesel generated electricity supply price reveals that the price of diesel fuel is the most sensitive assumption. There is nearly a one to one correspondence between a change in the diesel price and the change in the supply price. Varying the conversion efficiency also has a significant impact on the supply price. The diesel fuel escalation rate and the O&M costs were found to have very small effects upon the supply price.

4. FINANCIAL ANALYSIS

The methodology used in the financial analysis involves a discounted cash flow analysis and includes the calculation of an after tax rate of return based on 100 percent equity financing. An arbitrary rate of return (or "hurdle rate") of 15 percent has been assumed in order to judge the financial viability of these projects. Two actual project cases are analyzed in this section with a sensitivity calculation on the first case. The data are summarized in Table 5. The first case is the proposed Adecon wind farm consisting of 24 - 125 kW machines (3 MW total) located on the Magdalen Islands. The same wind farm was also assumed to be located on PEI in order to determine its viability there. Total installed costs, average wind velocity and the expected power purchasing rate vary between the two locations. The Magdalen Islands installation is assumed to cost $1382/kW. The site is expected to have a mean annual wind speed of 9 m/s, and the expected buyback rate is 9c/kWh. Assuming 90 percent availability, annual operating cost of $140,000, a tax rate of 19 percent, and a 6 percent declining balance capital cost allowance (Class 2), the internal rate of return for this project is almost 12 percent, marginally unattractive from a financial perspective.

The project results were recalculated to reflect the possibility of the construction of an underwater cable by 1991 to serve the Island. The buyback rate is decreased from 9 to 4c/kWh to reflect the expected value of wind energy after the cable is installed. The financial return decreases significantly to only 4.24 percent.

The modified assumptions for the same project located in PEI are a total installed cost of $1244/kW (10 percent reduction to reflect easier site access and installation), annual operating cost of $93,000 (2.5 percent of capital), an average wind speed of 6.3 m/s and a buyback rate of 5.5c/kWh. With these changes, a positive rate of return cannot be calculated, indicating the project is not a financially attractive investment. In order to achieve an internal rate of return of 15 percent, the PEI project would have to cost only $1.06 million

TABLE 5

DATA ASSUMPTIONS AND FINANCIAL ANALYSIS RESULTS FOR THREE CASE STUDIES

	Fort Severn	Iles de la Madelene	PEI
Project Data Assumptions			
Wind Turbine Manufacturer	Howden	Adecon	Adecon
Turbine Rated Capacity	60 kW	24 x 125 kW	24 x 125 kW
Average Annual Wind Seed	5.8 m/s	9.0 m/s	6.3 m/s
Average Annual Energy Production	90,963 kWh	9,112,500 kWh	5,287,440 kWh
Financial Data Assumptions			
Total Installed Cost	$240,000	$4,145,000	$3,730,000
Total Installed Cost/kW	$4,000	$1,382	$1,243
Annual O&M Cost	$5,000	$140,000	$90,300
Tax Rate	40%	19%	19%
Depreciation Schedule	Class 2	Class 2	Class 2
Power Purchase Rate	40c/kWh	9c/kWh, 4c/kWh after 1990	5.5c/kWh
Annual Revenues	$36,385	$829,125 $364,500 after 1990	$290,809
Analysis Results			
Internal Rate of Return	7.11%	4.24%	N/A
Supply Price	30.4c/kWh	5.8c/kWh	8.4c/kWh
Internal Rate of Return (9c/kWh constant rate for Iles de la Medeleine)		11.79%	

($353/kW). Alternatively, at a capital cost of $1000/kW, the buyback rate would have to be slightly higher than 12c/kWh in order to achieve a 15 percent rate of return.

The second case is an installation at Fort Severn of a Howden 60kW turbine at an assumed total project cost of $240,000 ($4000/kW). In this instance, Howden is expected to sell the electricity to Ontario Hydro at their avoided cost of 40c/kWh. The average annual wind speed is 5.8 m/s (13 mph). Assuming a 40 percent corporate tax rate (due to a large parent company) and Class 2 capital cost allowance treatment, the internal rate of return is 7.11 percent. If a rate of return equal to 15 percent is required, the installed cost must fall to $135,000. Even at a tax rate of 19 percent, the internal rate of return remains below 10 percent.

The financial analyses for these case studies were rerun with Class 34 capital cost allowance treatment instead of Class 2. Class 34 availability marginally increases the rate of return for each of the projects. For example, the Fort Severn project return rate increases from 7.1 to 10.7 percent with Class 34. The increases do not appear to be large enough to dramatically increase each project's financial attractiveness.

These analyses indicate that, at present, wind energy is generally financially unattractive. There are, however, exceptions to this conclusion, particularly for areas with high diesel costs or high utility purchase prices and most importantly those locations with very good wind regimes.

5. MARKET CONSTRAINTS AND OPPORTUNITIES

The current energy contribution from wind systems installed in Canada is estimated to be about 11 TJ (3 million kWh or 1800 BOE) from about 1400 kW of installed capacity. The current contribution is from small scale systems installed across the country, as well as from larger systems (50-500 kW range) installed as demonstration projects or for research and development purposes.

The addition of Project Eole, expected to be operational sometime during the next 12-18 months, will quadruple the contribution of wind energy to Canada's energy supply. Other demonstration projects proposed or underway at Fort Severn, Magdalen Islands and other locations will add to the contribution total over the next few years, with total installed capacity perhaps reaching 10-12 MW before 1990.

Beyond these proposed or planned demonstration projects, domestic market prospects are at best uncertain. The preceding analysis has shown that the economic viability of wind energy systems is highly sensitive to capital costs, wind regimes and power purchase rates. The economic analysis suggest that wind turbines are likely to be economically attractive in remote community applications for a reasonable range of current capital cost data, power purchase rates and wind regimes. However, the financial analysis in this paper for the one example remote community project (Fort Severn) shows that the project has a relatively low rate of return, and it could be reasonably concluded that this demonstration project would not have proceeded without funding support from Government. The project is receiving a $200K contribution through a 50/50 cost-sharing arrangement between EMR and the Ontario Ministry of Energy, with EMR's funding coming through the Remote Community Demonstration Program (RCDP). Obviously, the capital cost of this project is much higher than the cost data assumed for other wind machines in the supply price analyses. A significant reduction in the capital cost (to $2800/kW) to represent a potential replication cost would dramatically improve the economics of this project to make it almost attractive without a grant from a financial perspective.

Wind energy projects could be financially attractive for communities with better wind regimes than Fort Severn (5.6 m/s), although the effects of an improved wind regime would be partially offset by the significantly lower diesel fuel costs in most other communities (Fort Severn at $1.10/litre). This analysis would suggest that capital costs must be below $2000/kW with buyback rates in the 10-15 cent per kWh range (about 50c/litre of diesel fuel) to make investments in wind systems attractive for a greater number of remote communities. This cost level would appear to be achievable, so that the number of wind systems serving remote communities is likely to increase over the next few years as the results of demonstration projects are disseminated to a wider audience and other information, technical and institutional constraints are addressed through the established federal programs.

It is possible that 10-20 wind systems might be installed in remote communities between now and 1995, involving 2 MW of capacity and total wind turbine sales of about $2 million. While the actual number of systems installed may be a bit less or even significantly larger than this estimate, we believe the remote market on its own will not provide an adequate base on which to build a viable industrial capability in wind energy in Canada. A strong domestic manufacturing industry will only develop if successes from demonstration projects put Canadian manufacturers and developers in the position to successfully penetrate one or both of two much larger potential markets: grid connected supply and the global export market.

The preceding analysis has shown that wind system costs must fall a considerable amount (below $1000/kW) before grid applications can become economically viable. While production scale economies could contribute towards the required cost reduction, it is unlikely the isolated market opportunities are large enough to achieve the necessary economies of scale and reach prices that would encourage small power producers and/or Canadian utilities to look more favourably towards wind energy systems. Substantial third party investor interest is also unlikely to develop without considerable cost reductions because of the relatively high expected return rate to venture capital. Tax incentives could improve these returns, but our preliminary analyses suggest that relatively substantial new tax breaks would be necessary to make wind energy investments in grid supply situations financially attractive at the present time. However, it is possible that the availability of Class 34 and investment tax credits could help wind developers attract additional equity capital to increase the private share of demonstration project costs. The current climate of fiscal restraint and tax reform makes the implementation of such incentives very difficult, and further effort is required to develop a convincing rationale for these tax changes.

The export market appears to offer some promise if Canadian technology can become and remain competitive. Recent market studies have estimated a significant global market for wind energy in rural applications and for grid supply, and manufacturing companies in many countries are pursuing this market. Canadian technology appears to be potentially competitive in these markets, but preconditions such as proven reliability and performance remain to be met before this market will open.

The constraints to the domestic market penetration of wind energy systems and possible solutions to address these constraints are summarized in Figure 2. The key requirement for significant market activity is to achieve cost competitiveness with utility supply sources, and R&D and other program actions which improve cost/performance, reduce risks and increase reliability are the most likely solutions.

FIGURE 2

CONSTRAINTS & POSSIBLE SOLUTIONS TO DOMESTIC MARKET PENETRATION

CONSTRAINTS	SOLUTIONS
HIGH SYSTEM CAPITAL COST	R&D TO ACHIEVE TECHNICAL IMPROVEMENTS IN SYSTEM COST/PERFORMANCE DEMONSTRATION PROJECTS TO IMPROVE SYSTEM RELIABILITY, REDUCE INVESTMENT RISKS INCREASED MARKET TO ACHIEVE PRODUCTION ECONOMIES
INADEQUATE FINANCING (HIGH COST OF VENTURE CAPITAL)	FISCAL INCENTIVES TO IMPROVE PROJECT RETURN RATES (GRANTS, LOANS, LOAN GUARANTEES, TAX INCENTIVES)
INADEQUATE/UNKNOWN WIND REGIME	IMPROVED INFORMATION AND DATA ON SITE SPECIFIC WIND POTENTIAL
TECHNICAL UNCERTAINTY (RELIABILITY, PERFORMANCE)	INCREASE OPERATING EXPERIENCE THROUGH SYSTEM TRIALS, TESTING (ATLANTIC WIND TEST SITE) DEMONSTRATION PROJECTS
POWER PURCHASE POLICY (COST OF CONVENTIONAL SUPPLY SOURCES)	PROVINCIAL ACTION TO ESTABLISH APPROPRIATE POWER PURCHASE POLICY (INCREASE BUYBACK RATES)

6. CONCLUSIONS

This paper has attempted to critically examine the economic potential for wind energy in Canada. The primary conclusions to be drawn from the economic and financial analyses contained in the paper is that there is some near term market potential for wind energy systems in remote community applications, but penetration into the domestic grid supply market is constrained by the relatively high costs of wind energy systems at the present time. There does appear to be considerable export market potential for wind machines, but certain preconditions must be met to successfully penetrate this market. The most important requirement for export market entry is domestic market success, which could be achieved through several successful demonstration projects.

These conclusions carry implications for the federal government's R,D&D program strategy in the wind energy area. For the remote market, there is an obvious need for the continuous development of site specific information on the wind regime near remote communities. Demonstration projects, system monitoring and information transfer are also necessary activities to increase familiarity with wind systems and "prove up" performance capability.

For the grid market, the obvious requirement is to explore the possibilities for reducing wind turbine costs and increasing wind system performance. The program activities would include R&D projects to obtain further technnical improvement and system trials and monitoring to assess performance. The cost targets are challenging and EMR plans to investigate the opportunities for cost reduction through a contracted study. Demonstration projects in remote communities and locations with favourable wind regimes and/or high costs for alternative electricity sources could serve an interim role in proving up system reliability and further developing industrial capability to allow Canadian manufacturers to expand their markets.

The system cost levels required for larger scale domestic market penetration could be achieved over time with improved system cost/performance and increased production levels to obtain some economies of scale. The timing for this market activity is uncertain. Provincial action to increase power purchase rates in specific jurisdictions could assist the medium term market development for wind systems, but immediate rationalized rate increases will not have a dramatic effect on the number of wind energy projects to be implemented over the next few years. The preliminary results of our analysis work suggests other forms of fiscal incentives could also be helpful, particularly in attracting equity capital for the private cost share of demonstration projects.

SWECS STANDARDS

WILLIAM PORTER
CANADIAN STANDARDS ASSOCIATION
STANDARDS ADMINISTRATOR

As CSA Project Manager for the development of renewable energy Standards, it is my role to administer this program and to encourage its advancement.

I am fortunate to have a group of volunteers who are dedicated to the development of wind energy technology and who recognize the significance of good standards in the long-term acceptance of wind energy.

Progress to date has been most favorable thanks to the people involved. For a new frontier program such as this, my superiors and my peers have been impressed with the high level of volunteer support and the conscientious effort on the part of all concerned.

With a little bit of luck and perserverance, we might meet the goal of having four preliminary standards published by March 31, 1986. Two are certain to be ready, one is pretty sure, and the fourth depends on our Technical Committee meeting tomorrow. The details of that, I will leave to our panel participants.

I am sure most of you are already familiar with CSA. Many of you have been involved in CSA programs. However, for those of you who may not be so familiar with CSA, allow me a minute or two to provide some background.

The Canadian Standards Association is a large, independent, voluntary, not-for-profit, national organization made up of members from business, government, labor, the consumer sector, and other associations.

CSA has been preparing standards for 67 years and has provided testing, certification and inspection services for about 40 years. CSA is one of a very few such complete service organizations in the world.

Of the more than 700 people employed at CSA's head office in Rexdale, about seven per cent are employed in standards preparation endeavours: However, there are more than 7,000 people who serve -- on a voluntary basis -- on about 1,100 standards committees.

Without our members -- those volunteers who give of their time and talent to draft and maintain standards -- CSA could not exist.

In the development of standards -- the operative word is consensus. There is no question that consensus-style development of standards -- to arrive at the rules-of-the-game -- is increasingly favored by industry, regulators, and users alike.

The continuing adoption or acceptance of consensus standards by regulators, or owners, or specifiers, or users is proof that this approach is cost-effective. It is increasingly being regarded as the preferred method of reaching the compromises necessary for our society to function safely and efficiently.

A brief look at how CSA functions:

. our President, John Kean, answers to a Board of Directors, which includes a balanced matrix of government, industry, user, and general interest members.

. our Vice-President, Standards, George Lawrence, answers to the Standards Policy Board, which includes a balanced matrix of government, industry, user, and general interest members.

. skimming a few levels, I answer to the Standards Steering Committee on Solar and Wind Energy and the eight Technical Committees under its control. All of these committees include a balanced matrix of government, industry, user, and general interest members.

As you can see, consensus and the balanced matrix for decision-making are almost synonymous.

The Steering Committee sets goals and objectives, ensures due process by the Technical Committees and monitors progress. It appoints Technical Committee chairmen and has the final say on publication of standards under its control.

Technical considerations are the prerogative of each Technical Committee. Letter ballot or voting on the content of the standard is the sole responsibility of the Technical Committee. Technical comments from the Standards Steering Committee or the public must be tabled to the Technical Committee.

The publication of a formal National Standard of Canada requires a double-level ballot -- two-thirds approval by the Technical Committee and 60 per cent approval by the Standards Steering Committee.

One of the major strengths of CSA is that any standard is considered a living document -- subject to continuing review and upgrading by its Technical Committee. All comments received must be tabled into the consensus process.

The Technical Committee on Wind Energy Conversion Systems (WECS) has opted initially to publish preliminary standards. This is often done in new technology areas to provide a period for thorough public review and comment prior to publication as a formal standard. A preliminary standard exists usually for a period of about one year.

Funding for standards development is on the basis of in-house cost. The National Research Council of Canada has funded this cost to date.

Before closing, two key players in this standards program should be complimented for their contribution:

. Mr. Marc Chappell of National Research Council, a true leader and pillar of strength in the development and support of this program;

. and our Technical Committee Chairman, Malcolm Lodge -- for his determination to make these standards world-class documents.

Compliments also should go to our four Sub-Committee Chairmen, who have devoted innumerable hours of their own time, and considerable expertise, to make their standards a reality.

. Raj Rangi, standard F416 -- Safety Design Criteria and Operation -- now published.

. Ray Richards, standard F417 -- Performance

- Jim Lea, standard F418 -- Interconnection to the Electrical Utility.
- Don McKay, standard F428 -- Siting Guidelines.

PERFORMANCE SUB-COMMITTEE - SMALL WIND ENERGY CONVERSION SYSTEMS

Ray Richards
National Research Council

A Sub-Committee on WECS Performance Standards was put together about two years ago by the Canadian Standards Association. The Committee is composed of individuals representing the different interest groups that the CSA requires for such Sub-Committee. I'd like to introduce these members to you just by reading their names and identifying the particular interest group they represent. First of all, Professor Terry Base, from the University of Western Ontario is on our committee and represents a researcher in the field of wind energy. Secondly Dave Baker of the Alberta Research Council representing the wind test site for water pumping stations located near Lethbridge Alberta. Thirtly we have Robert Kelland of the Colleges of Trades and Technology in Newfoundland, representing again the researcher interests.

In terms of manufacturers we have Mary Ellen Jones of DELTX Windpump Corporation, Calgary Alberta, Brian Richards, of Shawinigan Consultants Inc. and Lawrence Schienbein, formerly manager of wind energy engineering at DAF-Indal Ltd and now with SERI in the U.S. Consumer representation was provided by Victor Wagner who is a WECS hobbyist and proponent of wind energy systems and who gave valued objective input in the development of the standard. Peter South of ADECON Inc. formerly wind energy a researcher at the NRC also gave valued assistance with the development of the standard as a subcommittee member. Finally, Bill Porter CSA Standards Administrator and myself as Chairman, initially representing a wind test site and later the National Research Council.

Before I get into the index of our performance standard, I think it might be appropriate to review the scope of the standard.

First of all, this particular standard specifies methods for determining and reporting performance characteristics for wind energy conversions systems. This standard applies to WECS having mechanical, electrical or thermal output. This standard is not concerned with noise generated by the WECS except ot report the overall noise level and the procedure used to measure that noise level. The standard is not concerned with the siting or installation of a WECS and it is not concerned with the electro-magnetic interference that may result from the use of a wind turbine.

Now that I have covered the scope it might be appropriate then to look at the index of the standard.

I've outlined the scope, which is section one.

Definitions, section two, we found to be an extremely important aspect of the standard. Without proper definitions you can't logically and intelligently discuss any standard.

Skipping to section 5, the field test method describes essentially the installation and specification of instrumentation for each of the various parameters that are measured in the field test. For example:

- the windspeed
- the anemometer in Section 5.4.1
- its location and power monitoring, Section 5.5
- Temperature Monitoring, Section 5.6
  and
- Atmospheric Pressure Montoring in the same Section.

The majority of our time in the development of the standard was spent on Section 6 which identified the procedure used to determine the performance curve of a WECS in the real wind. In particular, Section 6.4.1, the "method of bins". This method was borrowed essentially from the AWEA and IEA standards which were in existence at the time that the CSA standard was considered. Both of these standards provided an excellent foundation on which bo build the CSA standard. In many respects they helped rid us of the task of building some of the more minor aspects of the standard. This allowed us to concentrate the majority of our time on the meat of the standard , which is really the procedure to measure the performance curve.

It also gave us an apportunity to look at other methods that can be used to establish a performance curve. In particular: the running average method, the method of most probable power and the energy method which have all been described at one time or another in the literature.

However the "method of bins" was considered to be the most appropriate method for our investigation because of its popularity. As it turned out, through some of our own computer simulations and other investigations, we found it to be as good as any method.

No one particular method that was investigated turned out to be more appropriate than another in terms of user-friendliness or in terms of the accuracy of the prediction of the performance curve. So, no particular preference was given to any one method based on that criterion, however since the "method of bins" has been around for quite a few years, and is in popular use, the CSA standard decided to adopt that particular method.

Because we had the IEA and AWEA standards to build on, we looked at some of some of what we felt were shortcomings of both standards. We identified a few areas.

First of all, there seemed to be no consistency in determining minimum data base requirements. We looked at this question for quite some time and finally decided on the method of defining a confidence interval on the data within each bin. The procedure arrived at is outlined in section 6.5.2 of the standard.

We looked at possible corrections to the performance curve due to turbulence effects and non-linearities in the performance curve of the turbine. However, since we had no real, hard experimental data to support the theoretical considerations, we opted not to include them in the standard at this time. Incidentally a volume of suplementary notes covering various technical issues raised by the subcommitee and papers presented is available on request from the CSA.

Another thing we looked at was the averaging interval used for the data. The AWEA standard recommends the use of 10 minute averages. Our investigations showed that it doesn't really matter which averaging interval is used. Just about any averaging interval between those two limits is satisfactory. In the end we opted for the ten minute average, in keeping with the International Meteorological Standard, and that was basically the only reason we adopted that for the averaging time.

There were also some considerations with respect to air density corrections that are performed in both AWEA and IEA standards. These create some problems, particularly with respect to cut-in winspeed for a turbine.

If one applies the adjustments that are recommended in the IEA of AWEA standard to power measurements, one finds that you can overpredict the maximum power or the installed power of the turbine just through the corrections to standard conditions.

Also by shifting the power curve vertically you can change the cut-in windspeed of the turbine. The cut-in windspeed can only be correctly accounted for by adjusting or correcting the performance curve with respect to the dynamic pressure on the blades at cut-in. This is something that we are presently looking at. We hope to include it as a revised version of the preliminary draft standard which we have produced to this date.

Basically I've covered: the general scope of the standard, the areas that we've looked into, the differences between the standards. I think that we've come up with a standard that combines the best of the existing standards, IEA and AWEA standards, and extends the standards a little further.

Technical Committee on Wind Energy Conversion Systems

Subcommittee on Performance of Wind Energy Conversion Systems

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Highlights of the Preliminary Small Wind Energy Conversion System (SWECS) Safety, Design and Operation Criteria
(CSA Standard F416)

R.S. Rangi, Chairman,
SWECS, Safety Subcommittee,
(National Research Council of Canada)

Presented at

CANWEA Annual Meeting
December 9 and 10, 1985
Skyline Hotel, Ottawa, Ontario.

1. Introduction

The increasing use of Wind Energy Conversion Systems (WECS) as a source of supplementing individual and national energy needs requires that safety, design and operation criteria be provided to assist in their successful development and use. These criteria were developed by consensus input using national and international participants. The preliminary standard, while addressing the international criteria, also covers the specific requirements to meet conditions within the Canadian environment. This paper gives a brief outline of the C.S.A. Preliminary Standard (F416-M1985) published in May, 1985.

The purpose of the standard is to specify design criteria for safety of Small Wind Energy Conversion Systems (SWECS) with rated mechanical power of 100 kW or less. These criteria apply to all types of machines horizontal or vertical axis, that may extract electrical, mechanical or thermal power from the wind.

Particular attention is paid to features of the wind regime and ranges of design values appropriate to North America. The various modes of WECS operation and non-operation involving a different mix of environmental and loading parameters are also addressed.

This Standard was prepared by the Subcommittee on Safety of Small Wind Energy Conversion Systems under the jurisdiction of the Technical Committee on Wind Energy Conversion Systems, and the Standards Steering Committee on Solar and Wind Energy and was formally approved by these committees.

2.0 Scope

2.1 This Standard is concerned with the safety of Wind Energy Conversion Systems, including design and operation under specified environmental conditions.

2.2 This Standard is concerned with systems of 100 kW or less of rated power, mechanical, electrical or thermal.

2.3 This Standard is concerned with all sub-systems of SWECS including Protection Mechanisms, Supporting Structure and Foundation.

2.4 This Standard is concerned with the components and materials supplied by the manufacturers, with the adequacy of the assembly, installation, maintenance and operation instructions, and with the safety of the system after assembly according to those instructions.

2.5 This Standard is not concerned with siting of SWECS, utility requirements for interconnection to the power grid, SWECS performance, or effects of SWECS on the environment.

2.6 Compliance with this Standard does not relieve any person from the responsibililty of observing applicable local, provincial and federal regulations.

2.7 This Standard covers minimum requirements and is not intended for use as a complete design specification or instruction manual.

3.0 General Requirements

3.1 Rotor and support system conforming to this Standard must be safe life designed.

3.2 SWECS Controls and Protection Systems must be designed for fail-safe operation such that in the event of failure of a component, the machine will remain in a non-hazardous condition.

3.3 SWECS conforming to this Standard must be designed such that maintenance can be safely carried out by following instructions given in the SWECS manual.

3.4 A SWECS manual, appropriate to the particular machine, shall be provided by the manufacturer. The SWECS manual must contain information on erection, inspection, maintenance procedures, and special tooling. A specific sequence of procedures to commission a new or repaired SWECS must be prescribed. Detailed procedures must be given to check proper function of safety, protection systems and trouble shooting routines.

3.5 In addition to this Standard, SWECS located in severe environmental areas shall be evaluated against special criteria dictated by the site.

3.6 The procedures used to manufacture, transport and erect the SWECS shall consider loads, deformation and exposure to the environment of the components and assemblies.

4.0 Environmental Considerations

The following Environmental Design parameters are specified in the Standard.

(a) Survival Wind Speed
(b) Wind Shear
(c) Wind Gust Model
(d) Wind Directionality
(e) Temperature and Humidity
(f) Icing
(g) Lightning
(h) Earth Quakes
(i) Hail

Normal environmental conditions generally concern long-term system loadings and operating conditions. They need not represent of the critical design conditions.

To ensure safe machine operation, a SWECS shall be designed to remain operable following those extreme environmental conditions which are rare but real. A 100-year recurrence interval* for determining worst case environmental conditions is considered adequate.

---

* A 100 year recurrence interval implies that a WECS with a 20 year desired life will have approximately 20% chance of destruction during its lifetime.

5.0 Design Considerations

5.1 Design Load Cases

The following load cases account for the various operating and non-operating modes for which a SWECS shall be designed. Sound engineering analysis of these cases will require appropriate aerodynamic and structural models. Care should be taken in understanding the SWECS status in each case (operating or shutdown), and dynamic factors should be applied in excess of calculated static loads where appropriate.

The following load cases are considered appropriate:

a) Dead load of all supported elements.

b) Survival wind loading as per section 4 on all exposed surfaces and calculated consistent with National Building code and CSA-S37M.

c) Ice coating on all exposed surfaces to recommended coating thickness.

d) Static and cyclic loads transmitted from the rotor during normal operation at rated power, and wind loads on other components at opeating wind speed.

e) Loads associated with overspeed of 10% greater than the maximum controlled overspeed allowed by the protective control system, on rotor and on othr components..

f) Maximum static and cyclic loading in 3 sec gust conditions while in operation.

g) Loads experienced during normal starts and stops.

h) Loads due to braking, feathering and furling etc. experienced during emergency shutdown.

i) Loads experienced during transportation, handling, erection and servicing operations.

j) Seismic Loading

The above load cases (a) to (j) are all specified (or service) loads.

5.2 Loading Combinations

The design of the SWECS rotor and the support structure shall consider the following combinations of loads (defined in 5.1).

i) = a + d Rated Power

ii) = a + d + g Normal starts and stops at rated power

iii) = a + b Survival wind

iv) = a + 0.5 b + c Full ice load and wind (wind loads based based on the iced sizes of members).

v) = a + e + f Overspeed and gust

vi) = a + e + h Overspeed and emergency shutdown

vii) = a + d + f + h Rated Power + gust + emergency shutdown

viii) = a + d + j Rated Power and seismic loading

Sound design practice shall require that loading cases be applied over the design safe operating life of the SWECS. Combined load case analyses shall include appropriate loading recurrance intervals.

Cyclic or frequent loads shall be considered to act over the intended life of the SWECS and used for the fatigue life design. Design for all other loads that act once only may be made using "allowable stress" or "limit states" methods.

6. Component Design

6.1 Rotor and Support Structure

This section outlines the minimum design requirements for the for the rotor, the support structure, anchorage and the foundations.

6.2 Electrical Systems

This section applies to SWECS used for generation of electricity including the following uses:

Battery charging
Supply of electricity to power conservation equipment
eg. (inverters, motor generators)

Feeding load (eg. resistence heating)

Utility grid connnection

7. Tests and Reporting

Each SWECS model shall undergo shop tests and 12 months of testing to ensure a sound structural design, a vibration free machine and safe operation of control and emergency subsystem.

The test shall include simulated fault conditions to test the control and protection system. The test period shall also include representative weather conditions.

The test program must be documented and the report shall follow guidelines established in the Performance Standard.

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MINUTES

from the

CANWEA FIRST ANNUAL GENERAL MEETING

THE
CANADIAN
WIND ENERGY
ASSOCIATION

CANADIAN WIND ENERGY ASSOCIATION

First annual general meeting held at the Skyline Hotel in Ottawa on December 8, 1985.

MINUTES

The following Directors were present at the meeting:

Malcolm Lodge - President,
Alex Printzios - Treasurer,
Vince Lacey - Secretary,
Mary Ellen Jones
Albert Watts.

V. Lacey distributed copies of the Agenda (copy attached) and bylaws to all of the members present during the meeting.

Introduction

M. Lodge called the meeting to order and introduced the Board of Directors. M. Lodge announced the following two additions to the Agenda.

1) Election of an industry representative to serve on the Energy, Mines and Resources (EMR) Technical Advisory Council.

2) M.E. Jones to provide a review of Alberta's Small Power Producers' Association (SPPA) activities.

M. Lodge requested agenda modifications from the membership and none were requested.

M. Lodge summarized the minutes of the 1984 Canwea Charter Meeting and advised that the details were included in the 1984 Conference proceedings.

M. Lodge briefly discussed the objectives for Canwea as printed in the 1984 proceedings, the Foundation Committee that led to the Charter Meeting in December of 1984, the election of the current Directors and subsequent appointment of officers.

M. Lodge requested a motion for acceptance of the 1984 proceedings and this was seconded by Monique Carpentier. The motion was carried.

M. Lodge revealed that the registration fees and list of paid registrants from the 1984 Conference had not been given to Canwea by the Conference organizers and since Canwea did not know which attendees listed in the 1984 proceedings had paid or not paid, it was decided that all attendees were accepted as members for 1985, but this would be rectified in January 1986 when membership fees are due.

President's Report

M. Lodge discussed Canwea's first year of activity which included incorporation under the laws of Canada, production of bylaws, an application for non-profit status, and the opening of a bank account. He explained that any two of the three officers were required for signing authority.

David Hoffman was requested to produce a quarterly newsletter and two issues have been distributed so far.

The Canwea Conference organization activity was tendered competitively and won by Passmore Associates who are doing a fine job.

Canwea became a member of the Conservation/Renewable Energy Industry Council (CREIC) in an effort to have wind energy represented at senior government meetings on the renewable energy industry.

EMR contracted with Canwea for $5,500. to produce a wind energy fact sheet which Canwea subcontracted and expected to earn a profit of between $500. and $1,000.

A membership drive organized by A. Printzios was conducted in the late summer of 1985.

Plans for 1986

M. Lodge advised the membership that the newsletter would be produced at least quarterly and possibly more frequently. Membership in CREIC would be continued to carry on with the lobbying effort at the appropriate government levels. Canwea would become more involved with information transfer and would try to obtain contracts to perform that work.

A wind energy workshop would be organized for 1986. Canwea plans to hire a part-time Executive Director to assist in carrying out these objectives.

Questions and Answers

Collin Kerr asked who the subcontractors were for the EMR Fact Sheet. M. Lodge advised that they were David Hoffman and Bryson Brown.

Charles Walker asked what arrangements for information transfer had been made with the American Wind Energy Association and the European Wind Energy Association. M. Lodge advised that informal contracts had been established with both of these organizations, plus the various wind test sites in Europe.

Marc Chappell advised that the President's Report had not been accepted. M. Lodge called for a motion which was seconded by Marc Chappell and the motion was carried.

Treasurer's Report

A. Printzios discussed that late incorporation permitted him to establish a bank account only in the summer of 1985. The financial position was detailed as follows:

Revenues	$8,900.
Expenses	$6,055.
Balance	$2,845.

Sources of revenue were membership fees, EMR contract and some conference registration fees. In 1985 new memberships included 11 corporate, 2 associate, 7 individual and 1 student, providing $3,720. of revenue. Canwea had received $2,975. from EMR for Phase I of the Fact Sheet, $1,805. from conference registrations and $400. from conference exhibitors. Due to financial constraints, expenses had been kept to a minimum. (Budget details attached).

Canwea was anticipating $12,000. from EMR for conference support and $2,975. for Phase II of the Fact Sheet. $10,000. is expected from the Ontario Ministry of Energy for the publication of the newsletter and $10,000. is expected from the National Research Council for the publication of conference proceedings.

M. Lodge concluded that the anticipated balance for December 31, 1985 would be between $5,000. and $15,000. and that a financial statement would be delivered to the membership in the new year.

Questions and Answers

Charles Walker asked if Canwea had budgeted for memberships in other wind energy associations. M. Lodge advised that there were no plans for this, but individual Canwea members were already members in the American Wind Energy Association (AWEA) and the European Wind Energy Association.

S. Qruaeshi put forth a motion to accept the Treasurer's Report, which was seconded by C. Brothers and subsequently carried.

Bylaws

M. Lodge tabled the bylaws and asked the membership for questions and comments.

Questions and Answers

Collin Kerr asked if clause 3.7a, restricted a company from displaying its membership in Canwea on his company letterhead. M. Lodge advised that this was the case. Collin Kerr asked Tom Gray how AWEA handled this and Tom responded that AWEA encouraged the display of AWEA on member companies' letterhead, but discouraged use of the name as product, or company endorsements.

M. Chappell suggested that clause 3.7b, allowed the use of the Canwea name if approved by Canwea's directors.

Collin Kerr claimed he would accept the bylaws if clause 3.7a was amended to permit on a company letterhead that the company is a member of Canwea. M. Lodge suggested that the board should be able to edit the text.

Charles Walker suggested that AWEA's Standards Committee looked after this issue in their organization to relieve the Board of Directors of this responsibility. Tom Gray said it was handled at AWEA in the Ethics Committee.

M. Lodge advised that there was no mechanism to amend the bylaws at the meeting and suggested Collin Kerr submit a request for this to Canwea so it could be considered for the next general meeting.

Charles Walker suggested that the matter be referred to the Canadian Standards Association (CSA) Wind Energy Committee. M. Lodge responded that that did not have anything to do with CSA and that Canwea did not want to be involved with product approval.

David Hoffman asked if a member may state "the company is a member of Canwea" if it was approved by the Canwea Board. M. Lodge responded "yes".

A. Printzios suggested the establishment of an Ethics Committee.

S. Qruaeshi suggested that the wording is too general. M. Lodge requested an amendment from Collin Kerr according to the bylaws and this would be ruled on at the next general meeting.

M. Carpentier pointed out that clause 6.1 should be modified to permit a male or female president and S. Qruaeshi added that the same problem existed in the bylaws for the position of vice-president. Charles Walker suggested that the bylaws be edited to eliminate this problem. M. Lodge agreed.

M. Chappell moved for the bylaws to be accepted and this was seconded by Collin Kerr and subsequently carried.

1986 Budget

M. Lodge stated that the 1986 budget was preliminary and subject to revision depending on the outcome of the conference and proposals. This situation will be avoided. For 1986, a quarterly newsletter would be produced at a cost of $125. per issue. Canwea expected to hire a part-time administrator and estimated the following other cost accounts:

Office rental	$1,200.
Clerical	$2,400.
Supervisory activity	$1,200.
Office supplies	$1,600.
Telephone	$1,600.
Travel expenses	$3,200.
Contingencies	$1,000.
Newsletters	$5,000.
TOTAL	$17,200.

Questions and Answers

Collin Kerr asked if Canwea intended to rent office space.
M. Lodge responded that Canwea was considering sharing office space in Ottawa with organizations like SESCI.

M. Lodge committed to advise the membership of any change in the budget.

M. Chappell noted a cost account for CREIC membership was not included in the budget and M. Lodge advised that this was an oversight as Canwea intended to retain its membership in CREIC.

M. Carpentier made a motion for acceptance of 1986 budget which was seconded by M. Chappell and carried.

Industry Representative for EMR's Technical Advisory Committee (TAC)

M. Lodge tabled that at EMR's conference in Montebello, a request was made to Canwea to identify an industry technical member to join the Technical Advisory Committee. The Committee currently consists of M. Chappell, A. Watts, M. Lodge, J. Rentfield, M. Carpentier and S. Pnevmaticos.

M. Carpentier explained that the positon would require a few days per year to assist EMR in directing the R.D. & D. Program.

M. Lodge asked for nominations and for those nominations to be seconded. M. Carpentier suggested that an alternate be elected as well in case the first elected could not attend.

M. Lodge asked for a vote to determine whether a non-attending member could be nominated. The vote was in favour of this.

D. Hoffman nominated C. Kerr and this was seconded by A. Printzios.
V. Lacey nominated D. Malcolm and this was seconded by B. Saulnier.
A. Printzios nominated S. Qruaeshi and this was seconded by A. Watts.

M. Lodge explained the voting procedure and A. Printzios read the list of eligible voters.

M. Chappell and Clint Coleman were appointed as scrutineers and they collected and counted ballots.

The winner was D. Malcolm and Saheed Qruaeshi was second.

M. Chappell proposed a motion to destroy the ballots. This was seconded by C. Brothers and the motion was carried.

Directors' Election

M. Lodge called for a vote for the rotating director's position which was held by M.E. Jones and explained that the position would be for a three-year term.

A. Printzios nominated S. Qruaeshi and this was seconded by V. Lacey.
C. Kerr nominated M.E. Jones and this was seconded by A. Printzios.

Fred Vosper of Earth Energy Systems proposed a motion to close the nominations. This was seconded by M. Chappell and the motion was carried.

M. Chappell and C. Coleman were appointed as scrutineers and collected and counted the votes.

M.E. Jones was the winner.

M. Chappell proposed a motion to destroy the ballots. This was seconded by C. Brothers and the motion carried.

Small Power Producers' Association (SPPA)

M.E. Jones described the activity of the SPPA in trying to obtain policy changes in Alberta for selling electricity.

Questions and Answers

Collin Kerr asked if Canwea had to have audited statements to qualify for non-profit status and M. Lodge stated that he did not believe so. M. Chappell advised that he believed that the organization would have to file a statement, but it did not have to be audited.

M. Lodge proposed a motion for adjournment which was seconded and carried.

CANADIAN WIND ENERGY ASSOCIATION
FIRST ANNUAL GENERAL MEETING
7:30 p.m., SUNDAY, DECEMBER 8, 1985
SKYLINE HOTEL OTTAWA

AGENDA

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1. Call to Order
2. Review Agenda
3. Minutes from the December 10, 1984 Charter Meeting
4. President's Report
5. Treasurer's Report
6. Business
   i. Ratification of CANWEA By-laws
   ii. 1986 Budget
7. Election of Directors
8. Other Business
9. Adjournment

CANADIAN WIND ENERGY ASSOCIATION

BY-LAWS

1. NAME & CONSTITUTION

The name of the organization shall be the Canadian Wind Energy Association, hereinafter referred to as the Association.

2. OBJECTIVES

The objectives of the Association shall be:

(i) To assist the wind energy community including industry, research groups, potential users and the interested public with the dissemination of technical information, standards, and trade information.

(ii) To produce and publish a newsletter at least four times each year and to organize and hold an annual meeting and symposium

(iii) To represent the interests of the wind energy industry to municipal, provincial and federal governments in Canada, and to thereby encourage the adoption of equitable legislative and economic conditions for the industry.

(iv) To promote discussion and to disseminate information on wind energy studies, projects and products, through publications and meetings, for the benefit both of industry members and the general public.

(v) To compile and maintain a registery of wind energy studies and projects, particularly within Canada.

(vi) To foster links with similar organizations outside Canada.

3. MEMBERSHIP

3.1 The membership of the Association shall be divided into the following classes: Corporate Members, Associate Members, Members and Student Members.

3.2 The normal qualifications for Membership shall be evidence of payment of annual dues as set out in Section 4. At the discretion of the Directors, persons may be accepted as or offered membership as a Member in return for services offered or for honorary reasons.

3.3 Membership is open to all.

3.4 Student Membership is open to all who are pursuing full-time educational courses at School or University.

3.5 Corporate Members are allowed two votes for two individuals an Associate Members are allowed one vote at meetings.

3.6 Applications of candidates who wish to join the Association shal be made on a form approved by the Directors and submitted to th Membership Officer. The Membership Officer shall enter the names of all members in a register of members of the Association.

3.7 (a) No member of the Association shall publicize his membership thereof for the purpose of advertising.

(b) Without prejudice to the generality of By-Law 11 the decision of the Directors as to what constitutes advertising in all respects shall be final and binding on every membership. No advertising shall include any publication of membership of the Association made in order to promote commercial sales of wind energy equipment or services, or to give the impression that membership necessarily implies technical competence to give professional advice on any aspect of wind energy utilization.

4. SUBSCRIPTIONS

4.1 The fiscal year of the Association shall be the calendar year and the payment of membership dues shall become due on the first of April in each year.

4.2 Dues of members of the Association as set out in Attachment A shall be fixed from time to time by the Directors.

4.3 The Directors of the Association may fix a reduction for dues of members who are enrolled by the Association after the beginning of the fiscal year.

4.4 Any member who has not paid dues within two clear months of the date on which they become due shall be notified of the fact by the Membership Officer or the Treasurer of the Association by Letter and one month thereafter any member who has still failed to pay dues may be taken off the roll of the Association members forthwith.

4.5 All monies received by the Association including all donations to the Association and all profits accrued to the Association will be held by the Association for its own use in furtherance of the objectives for which the Association is established.

5. GOVERNMENT

5.1 The authority and responsibility for the transaction of the business of the Association and for its management shall be vested in the Directors, who, in addition to the powers and authorities expressly conferred on them by the By-Laws, may exercise all powers and do all acts in furtherance of the objectives for which the association is established, other than those herein expressly directed or required to be exercised or done by the Association in General Meeting.

5.2 The Officers of the Association shall be President, Vice President, Secretary and Treasurer.

5.3 The President and Vice President of the Association shall be appointed by the Directors and will remain in such office for a period of one year or until a successor duly appointed and takes office as herein provided. The President shall not normally serve for more than two years.

5.4 The Vice President, Secretary and Treasurer of the Association shall be appointed by the Directors and subject to termination of office by resignation or otherwise shall remain in such office for a period of three years or until their successors are duly appointed and shall take office as herein provided. The Secretary and Treasurer shall not normally serve more than two successive periods of three years.

5.5 The Directors of the Association shall consist of five elected Associate or Corporate Members of the Association and the immediate past President, who are in good standing.

5.6 Directors shall be elected as provided by By-Law 7 and subject to termination of office by resignation or otherwise shall remain in such office for a period of three years or until their successors are duly elected and take office as herein provided. Directors shall not normally serve for more than two successive periods of three years.

5.7 There shall be elections for at least one Director in any year.

5.8 The Directors of the Association shall commence their terms of office following the election as provided by By-Law 7.

5.9 The number of Directors shall be determined by the Association in General Meeting.

5.10 The Directors shall meet whenever summoned by the President, who may convene a meeting of his own accord, or shall do so by direction of the Secretary or on a written requisition signed by at least three Directors. Three members of the Directors shall form a quorum.

5.11 Each member present at a meeting of the Directors shall be entitled to exercise one vote. The President shall also exercise a further or casting vote if necessary.

5.12 To assist them in furthering the objectives of the Association, the Directors may appoint Committees from the membership of the Association with such constitution and terms of reference as the Directors may determine from time to time to advise them on aspects of the Association's affairs.

5.13 The Chairman of each Committee shall normally be a member of the Directors and shall be responsible for informing the Directors of the proceedings of each Committee and conveying the Committee's advice on such matters as the Directors may refer to it from time to time or on any other matter within the Committee's terms of reference.

6. OFFICERS

6.1 The President will normally act as Chairman of the Directors. He shall also preside at all meetings of the Association and it shall be his duty to represent the Association in dealing with outside agencies and to communicate to the Association such matters and suggestions as may tend to promote the welfare of the Association and to transact business on behalf of the Association as the Association or Directors, acting in accordance with these By-Laws, may direct.

6.2 The Vice President shall act in the place of the President in the event of his inability to act. It shall be the duty of any Director to perform such functions as may be delegated by the President.

6.3 The Secretary shall perform such administrative duties as the Directors shall direct and shall attend in person, or by deputy, all General Meetings of the Association and all meetings of the Directors and take the minutes of the proceedings. Such minutes shall be recorded and presented for confirmation at the following meeting. A book of minutes of all meetings will be kept by the Secretary.

6.4 The Treasurer shall have custody of the Association's funds and shall keep full and accurate accounts of receipts and disbursements and shall deposit all monies and other valuable effects in the name and to the credit of the Association in such depositories as may be designated by the Directors at a meeting. He shall disburse the funds of the Association as may be ordered by the Directors demanding vouchers in accordance with the form or forms authorized by the Directors for such disbursements and render to the Directors at its meetings, or whenever the President and other officers of the Association may require, an account of all his transactions and of the financial condition of the Association.

6.5 The Treasurer shall act as Membership Officer and shall be responsible for administering all matters concerned with the recruitment and enrolment of members, including maintaining a roll of the Association members as required by By-Laws. He shall collect all membership dues and shall inform the Directors of any member who has failed to pay his dues within the required period of time.

7. NOMINATIONS AND ELECTIONS FOR DIRECTORS

7.1 Nominations of candidates for election as Directors may be made at the Annual General Meeting. Nominations of candidates shall be signed by at least two voting members of the Association proposing the candidate and accompanied by an intimation in writing signed by the member nominated that he is willing to serve. For the purposes of nomination it is not necessary for any candidate or nominating member to be present at the Annual General Meeting.

7.2 A ballot shall be held at the Annual General Meeting to select the new directors from the list of candidates and the elected directors shall take office immediately after the meeting.

7.3 A Director who subsequently becomes an Officer must submit for re-election after term of office has expired if the total term as a Director has exceeded three years and the Director wishes to remain a Director.

7.4 For the purpose of creating an overlapping of terms of office of Directors so that continuity of experience and initiatives of the Directors are not reduced, the first five Directors elected at the Charter Meeting will serve for terms such that the two Directors obtaining most and second most ballots in the first election at the Association Charter Meeting shall serve for three years, the two Directors obtaining the third and fourth most ballots shall serve for two years and the Director receiving the lessor ballots shall serve for one year.

8. MEETINGS

8.1 The Annual General Meeting of the Association shall be held between September first and December thirty-first in each calendar year upon a date and at a time to be fixed by the Directors.

The Annual General Meeting shall:

(a) Receive from the Directors a full Statement of Accounts of the Association showing the receipts and expenditure for the previous fiscal year. The Annual General Meeting may by simple majority direct the Directors to obtain an audited statement of the Association's finances.

(b) Receive from the Directors a report of the activities of the Association during the said year.

(c) Receive from the Secretary a report on and the appointment of Officers of the Association in accordance with the By-law.

(d) Hold a ballot to select new Directors in accordance with By-law 7.

(e) Decide on any resolution which may be duly submitted to the meeting as hereinafter provided.

8.2 A Special General Meeting may be convened by direction of the Directors or on a written requisition to the Secretary stating the business for which the Special General Meeting is required and signed by not less than ten voting members. If the meeting so requisitioned be not convened within twenty-one days the said members may convene such a meeting. Ten voting members shall form a quorum.

8.3 At least fourteen days' notice of all General Meetings shall be given to all members, but the non-receipt of such notice by any member shall not invalidate the proceedings.

8.4 An advance copy of the Agenda shall be sent by common mail to each member and postmarked at least ten days prior to the date of all General Meetings but the fact that any member has not received a copy of the Agenda shall not invalidate the proceedings. Business which is not included in the Agenda may be discussed at the meeting only if:

(a) A simple majority of the members present are in favour thereof, and

(b) The business does not fall within the terms of By-Law 10.

8.5 Every Member present at the Meeting with a right to vote shall be entitled to vote according to Section 3.5. The President shall also exercise a further or casting vote if necessary. At all General Meetings except as provided by By-Law 10 a simple majority of votes will decide a resolution. Proxy votes shall be admissible at all General Meetings provided the business and resolution are included on the advance copy of the Agenda along with voting forms. Telephone, telex, faxcom or other usually accepted forms of electronic communication will be accepted as evidence of vote by voting members.

8.6 No one can take part in General Meetings unless he has been accepted as a member of the Association and has paid dues according to these By-Laws.

8.7 At any General Meeting a resolution put to the vote of the meeting shall be decided on a show of hands unless a secret vote is demanded before the act or declaration of the result of the show of hands: -

(a) by the President; or

(b) by motion of a voting member duly seconded by a voting member in person or by proxy; or

(c) by any voting member or voting members present in person or by proxy and representing not less than ten of the total voting rights of all members having the right to vote at the meeting.

Unless a secret vote be so demanded, a declaration by the President that a resolution has on a show of hands been carried, carried unanimously, or carried by a particular majority, or lost, an entry to that effect in the book containing the minutes of proceedings or the Association shall be conclusive evidence of the fact, without proof, of the number or proportion of the votes recorded in favour of or against such resolution.

The demand for a secret vote may be withdrawn by the voting member requesting the secret vote at any time.

8.8 On a poll votes may be given either personally or by proxy.

9. EXPULSION OF MEMBERS

It shall be the duty of the Directors, if at any time they shall be of the opinion that the interests of the Association so require, by letter to invite any member to withdraw from the Association within the time specified in such letter and in default of such withdrawal to submit the question of his expulsion to a meeting of the Directors to be held within six weeks after the date of such letter.

Directors shall be given at least seven days' notice that a question of withdrawal or expulsion is to be discussed at a scheduled meeting of the Directors. A member whose expulsion is under consideration shall be given at least seven days' notice of such a meeting and shall be allowed to offer an explanation of his conduct verbally or in writing. If the majority of the Directors members present then shall vote for his expulsion he shall thereupon cease to be a member of the Association.

10. AMENDMENTS

Any alternations may be made in these By-Laws by a General Meeting provided:

(a) That details of the proposed alteration or alternations are included in the notice of the General Meeting, and

(b) That the resolution proposing such alteration is carried by two-thirds of those present in person or by proxy and eligible to vote at the General Meeting.

11. INTERPRETATION

Every member binds himself to abide by the By-Laws of the Association and also by any modification thereof made in conformity with such By-Laws and also to accept as final and binding the decision of the Directors in all cases of dispute or disagreement as to the interpretation of these By-Laws.

12. DISSOLUTION

12.1 The Association may be dissolved by a Special General Meeting convened by the Directors or on the written requisition to the Secretary signed by a majority of the members.

12.2 If a resolution of dissolution be duly passed, the Directors shall forthwith liquidate the affairs of the Association and if there are any surplus assets on realization these shall be transferred to an Association with similar objectives or to a charity.

MINUTES

from the

CANWEA DIRECTORS' MEETING

CANADIAN WIND ENERGY ASSOCIATION DIRECTORS' MEETING

Following the 1985 Canadian Wind Energy Association Conference Annual Meeting, a Directors' Meeting was held to discuss various business matters and elect new officers.

MINUTES

Finance

A. Printzios presented the financial situation of Canwea and it was concluded that there were sufficient funds to pay all outstanding bills, assuming Canwea would receive Energy, Mines and Resources' financial support, which was expected immediately.

Proceedings

M. Lodge agreed to prepare an RFP for the publication and distribution of the proceedings.

Executive Officer

It was agreed that Canwea would approach CREIC to discuss sharing expenses for a part-time executive officer and to request through the next mail out to the membership and through the Canwea Bulletin, names of candidates who might perform as Canwea's part-time executive director. It was agreed that the part-time director should be based in Ottawa.

Newsletter

It was agreed that the next one should be in February and that the American Wind Energy Association should receive a complimentary copy.

Conference

It was agreed that the 1986 Canwea Conference would be planned to be held in Quebec City in the early fall.

Officers

M. Lodge offered to resign as the President of Canwea. His resignation was accepted.

M. Lodge nominated A. Printzios for President, which he accepted.

A. Watts accepted the position of Treasurer.

M.E. Jones accepted the position of Vice-President.

V. Lacey accepted the position of Secretary.